THE NATURE OF MOVEMENT AND ACTION ERRORS PRODUCED BY BRAIN-INJURED PATIENTS

BY

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For Shawn,
My gift from God

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August 1998

Chair: Leslie J. Gonzalez-Rothi, Ph.D.
Major Department: Communication Processes and Disorders

Some patients with brain damage produce action errors during activities of daily living. Investigators in recent research reports have examined the planning, organization, and production of these action errors through different theoretical models with different inherent assumptions and predictions, using different research hypotheses and evaluation criteria, and including subjects with heterogeneous etiologies of brain damage. The current study describes a proposed relationship between apraxia and pragmatic action that serves as a framework for the examination of the nature of movement and action errors produced by brain-injured patients. The hypothesized relationship between apraxia and pragmatic action can be divided into two parts--high level schemas associated with executive function, supervisory attention/working memory, and the conceptual knowledge of the relationship between tools and actions, and low level schemas associated with the praxis system which mediates learned skilled movements. Forty

subjects participated in this study--twenty left brain damaged patients (LBD), ten right brain damaged patients (RBD), and ten non-brain damaged control subjects. All subjects underwent an evaluation that measured high and/or low schema deficits and were videotaped while engaged in an activity of daily living, eating a meal. The videotapes were scored for presence of action and movement errors. Results indicated that both brain-injured groups significantly differed from the control group in total number of errors produced. The LBD group produced more tool errors than the RBD group while both the LBD and the RBD group produced significantly more non-tool errors than the control group but did not differ from each other. Additionally, production of specific error types during the meal correlated highly with a measure of high level schema deficits and a measure of low level schema deficits. Therefore, both high and low level schema deficits contribute to production of action errors. Additionally, the results appear to indicate that brain damage to either hemisphere can result in production of action errors in the natural environment.

CHAPTER ONE
REVIEW OF THE LITERATURE AND STATEMENT OF THE PROBLEM

Introduction

Purposeful movements, defined as intentional "changes in place, position, or posture" (Webster, 1981, p.747), that have direct purpose or aim, and goal-directed actions, defined as "acts of will accomplished over a period of time in stages" (Webster, 1981, p.12) are learned throughout life as people interact with their environment. The loss of the ability to produce purposeful, skilled movements as the result of brain damage has been termed apraxia (Rothi & Heilman, 1997). Liepmann (1920) defined apraxia as an impairment in the production of learned (or skilled) movements not caused by weakness, paralysis, incoordination, or sensory loss (Liepmann, 1920). Apraxia is manifested in a person's inability to "move the moveable parts of the body in a purposeful manner even though motility is preserved" (Liepmann, 1900/1977, p.161).

A deficit in the ability to produce goal-directed actions has been called frontal apraxia by Mayer, Reed, Schwartz, Montgomery, and Palmer (1990), Schwartz, Reed, Montgomery, Palmer, and Mayer (1991), Schwartz, Mayer, DeSalme, and Montgomery (1993), Schwartz, Montgomery, DeSalme, Ochipa, Coslett, and Mayer (1995), and Schwartz and Buxbaum (1997) and a deficit in managerial knowledge by Sirigu, Cohen, Duhamel, Pillon, Dubois, and Agid (1995), Sirigu, Zalla, Pillon, Grafman, Agid, and Dubois (1995, 1996), and Sirigu, Zalla, Pillon, Grafman, Dubois, and Agid

(1996). Specifically, both frontal apraxia and deficits in managerial knowledge were defined as impairments in the planning and sequential hierarchical organization of actions required to obtain a desired goal (Schwartz & Buxbaum, 1997; Sirigu *et al.*, 1995).

Mayer *et al.* (1990), Schwartz *et al.* (1991, 1993, 1995), and Schwartz and Buxbaum (1997) reported that brain damaged patients with frontal apraxia produce errors of action while performing goal-directed activities of daily living such as preparing coffee and brushing teeth. These learned, goal-directed actions were subsequently labeled "pragmatic action" by Schwartz and Buxbaum (1997). Ochipa, Rothi, and Heilman (1989) reported a brain damaged patient with ideational/conceptual apraxia who made errors of action while eating a meal and brushing teeth, both "pragmatic actions as defined by Schwartz and Buxbaum (1997). Foundas, Macauley, Raymer, Maher, Rothi, and Heilman (1995) reported that brain damaged patients with ideomotor apraxia made action errors while performing the pragmatic action of eating a meal. Each of the above studies documented action errors in goal-directed activities of daily living. However, each of the above researchers approached the study of action and action errors through different theoretical models with different predictions and assumptions. Mayer *et al.* (1990), Schwartz *et al.* (1991, 1993, 1995), and Schwartz and Buxbaum (1997) approached the study of pragmatic action through the Unified Hypothesis, a theoretical model based on the activation-trigger-schema (ATS) framework proposed by Norman and Shallice (1986). The ATS framework for production of action was derived from the study of normal subjects (Norman & Shallice, 1986). Ochipa *et al.* (1989) and Foundas *et al.* (1995) approached the study of

pragmatic action through the Cognitive Neuropsychological Model of Limb Praxis and Apraxia proposed by Rothi, Ochipa and Heilman (1991, 1997). The Cognitive Neuropsychological Model of Limb Praxis and Apraxia was derived from the study of brain injured patients (Rothi *et al.*, 1991). In order to systematically study errors produced during pragmatic actions, a theoretical model is needed that explains the relationship between frontal apraxia, conceptual/ ideational apraxia, and ideomotor apraxia and incorporates action information from the Unified Hypothesis (Schwartz & Buxbaum, 1997) and movement information from the Cognitive Neuropsychological Model of Limb Praxis and Apraxia (Rothi *et al.*, 1992, 1997). The resulting combined model can then be used to make predictions about pragmatic errors which can be subsequently studied. The purpose of the present study is to describe a theoretical model of pragmatic action based on Schwartz and Buxbaum (1997) and Rothi *et al.* (1997) which is then used as a framework to examine the nature of movement and action errors produced by brain-injured patients. Pertinent literature is reviewed relating to the genesis and growth of the study of movements and actions.

Review of the Literature

Historical Perspectives and Theoretical Models of Apraxia

Steinthal, in the late 1800s, was the first to use the term apraxia in describing a disturbance in skilled limb movements as the result of brain damage (cited in Hecaen & Rondot, 1985). Steinthal wrote that apraxia consisted of a disturbance in the relationship between movements and the objects upon which the movements were enacted (cited in Hecaen & Rondot, 1985). Subsequently, there was a lack of consensus in discussions of the mechanism for and definition of apraxia. For example,

other researchers had observed the disturbances of object related movements in aphasic patients but attributed both deficits to asymbolia, a generalized disturbance in the comprehension or production of symbols in any modality, including language and gesture (Finkelnstein, cited in Duffy & Liles, 1979; Critchley, 1939). Goldstein (1948) also related disorders of action to the patient's aphasia and included skilled movement problems within a definition of aphasia. Pick (1905), however, defined apraxia as an asymbolia which was not included within a definition of aphasia. Another mechanism proposed to explain apraxia was posited by Kussmaul (cited in Hecaen & Rondot, 1985) who defined apraxia as an agnosia, an impairment in the recognition of tools, which then affects the movements produced with tools. In 1905, Liepmann described a patient, who presented with a severe inability to produce volitional movements with the left hand as well as profound aphasia. Liepmann's point in describing this case was that a disorder of language or gnosis could not explain apraxia of only one hand. Movement failures created by language or gnosis deficits would affect both hands. Thus, Liepmann (1900/1977, 1905a/1980a, 1905b/1980b, 1907/1980c, 1920) was the first to describe the mechanism of apraxia as a disorder of movement planning.

Liepmann (1905b/1980b) studied 89 brain-damaged patients, 42 with left hemiplegia (thus suspected to have right hemisphere lesions), 41 with right hemiplegia (thus suspected to have left hemisphere lesions), 5 non-hemiplegic with aphasia (left hemisphere lesions), and one who was neither hemiparetic or aphasic but was apraxic. The patients were asked to produce three types of movements - 1) expressive movements such as waving and saluting; 2) transitive and intransitive movements to command (from memory) such as playing an organ grinder and snapping the fingers;

and 3) manipulations of actual tools such as combing hair with a comb and writing with a pen. Liepmann found that the patients with right hemisphere damage rarely made errors on these tasks whereas the patients with left hemisphere damage made frequent errors. Within the groups of patients with left hemisphere damage, approximately half showed evidence of apraxia and of these, twenty-five percent showed impairments when manipulating the actual tools (Liepmann, 1905b/1980b). Based upon these observations, Liepmann proposed that the left hemisphere, specifically the parietal region, was responsible for the skilled production of both hands (Liepmann, 1905b/1980b). He argued that the right hemisphere is dependent upon the plans and directives of the left hemisphere for learned movement and that the right hemisphere receives movement planning information from the left hemisphere via the corpus callosum. Liepmann proposed the existence of movement formulae which he defined as knowledge of the course of action (time-space sequences) required to complete an action goal as well as the semantic information about the tool and object used. The movement formulae may be implemented by retrieval of innervatory patterns (configurations of neural connections specialized for particular movement patterns) which communicate directly with the motor system for movement production (Figure 1-1) (Liepmann, 1905b/1980b).

Additionally, further support for Liepmann's proposal that the left hemisphere was responsible for the skilled movements of both hands was found in the case described by Liepmann and Maas (1907) of a patient with a lesion of the corpus callosum who was unable to produce skilled movements with his nonparalyzed left

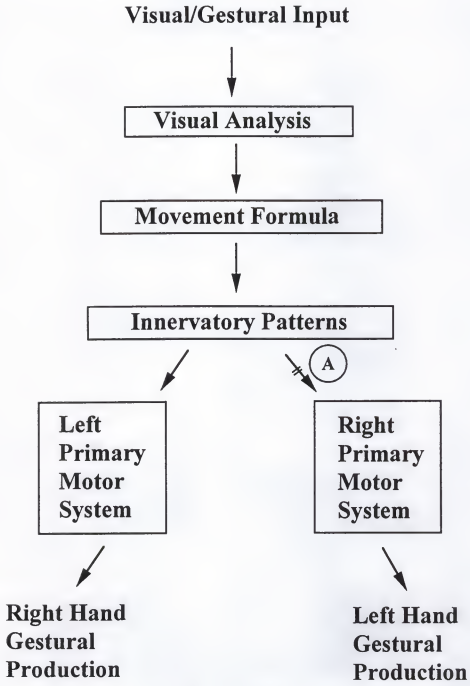


Figure 1-1. Liepmann's model of praxis (taken from Rothi, Ochipa, & Heilman, 1991).

hand. He was unable to write and could not even bring his hand into the writing position. The patient also showed deficits in using actual tools/objects. Liepmann hypothesized that the effect of corpus callosum lesion in this case was to disconnect the movement formulae of the left hemisphere from the primary motor cortex of the right hemisphere--lesion A in Figure 1-1 (Liepmann & Maas, 1907).

Subsequently, Liepmann (1905a/1980a, 1905b/1980b) described three subtypes of apraxia--limb kinetic apraxia, ideo-kinetic or motor apraxia, and ideational apraxia. Limb kinetic apraxia was described as a loss of the kinetic components of engrams resulting in coarse or unrefined movements with movements that no longer have the appearance of being practiced over time. Ideo-kinetic or ideomotor apraxia was described as a loss of the voluntary ability to perform learned movements. Ideational apraxia was described as an impairment of ideational (conceptual) knowledge resulting in loss of the conceptual linkage between tools and their respective actions as well as the ability to sequence correctly produced movements (Liepmann, 1905a/1980a, 1905b/1980b). Integral movements may be left out of a series, produced in the wrong order, or correct movements may be produced with the wrong tools (cited in Brown, 1988). By describing these praxis subtypes, Liepmann (1905a/1980a, 1905b/1980b) proposed that praxis is supported by a multicomponential system that can be differentially impaired.

Liepmann's proposals were resurrected by Geschwind in 1965 who discussed them in the light of new human and animal data. Geschwind supported the notion of the dominance of the left hemisphere for learned movement skill and of the existence of movement formulae or memories (stored representations). He also supported

Liepmann's statements that apraxia resulted from lesions in the dominant parietal region but argued that the important area was the underlying white matter pathways, specifically the arcuate fasciculus, and not the cortex.

Geschwind proposed that in the left hemisphere, the white matter pathway that runs deep to the supramarginal gyrus connecting the visual association areas and speech areas to the frontal lobes is the pathway by which motor responses are carried out in response to verbal and visual stimuli. These pathways terminate in motor association area, Brodman's area 6 (Geschwind, 1965). Movement information processed by area 6 is then relayed to the ipsilateral primary motor cortex, Brodman's area 4, as well as the contralateral motor association area, area 6. Movement information processed by contralateral area 6 is then relayed to it's affiliated primary motor cortex, area 4. (See Figure 1-2.)

Based upon this neural mechanism, Geschwind proposed that the apraxia of the left arm in a patient with right hemiplegia is not caused by the same lesion that caused the hemiplegia. Rather, the apraxia results from coincidental damage to either area 6, the callosal fibers connecting the left area 6 and the right area 6, or to the projections to area 6 from the parietal lobe. This argument implied that a lesion anterior to the left motor cortex which affects area 6 but spares area 4 should result in a bilateral apraxia. However, Geschwind stated that as of his writing, no such cases have been described presumably because lesions of left area 6 would most likely also affect area 4 due to their anatomical contiguity.

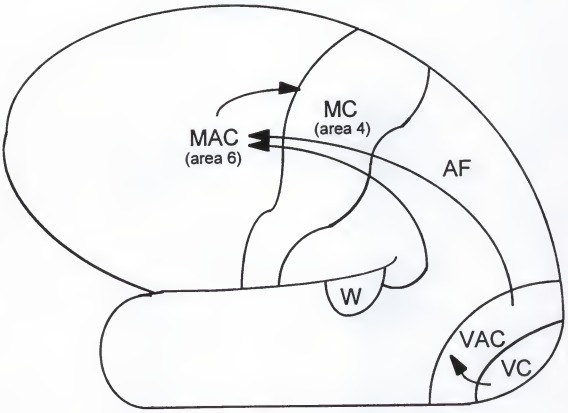


Figure 1-2. Geschwind's model of praxis. Lateral view of the left hemisphere. AF = arcuate fasciculus; SMA = supplemental motor area or motor association cortex; MC=primary motor cortex; VAC = visual association cortex; VC = primary visual cortex. The arrows indicate major connections of the areas shown (from Heilman & Rothi, 1985).

Assuming that visuokinesthetic engrams (Liepmann's movement formulae) of the left parietal lobe are important for correct production of gesture as well as critical to the decoding of seen, familiar gestures, Heilman, Rothi, & Valenstein (1982) postulated that damage to the visuokinesthetic engrams would result in difficulty with both the comprehension and production of gesture. The authors argued that measuring a patient's ability to discriminate well-performed from poorly performed movements may enable the clinician to determine whether or not a patient's apraxia resulted from destruction of these engrams through lesions involving posterior cortical regions: specifically left parietal lobe. An apraxic patient with preserved visuokinesthetic engrams would be able to discriminate between good and poor performance while an apraxic patient with damage to the visuokinesthetic engrams would not be able to make that discrimination. The authors tested this theory by giving 20 apraxic subjects a gesture discrimination test. The examiner named a target action and the subjects were asked to watch a videotape of gesture performances and choose the performance out of three possible for each command that best represented the named target. Patients with more difficulty discriminating the gesture productions had posterior lesions (and presumably damaged visuokinesthetic engrams.) Based on these results, Heilman *et al.* (1982) discussed the possibility of two types of ideomotor apraxia: one type which presents with poor production and comprehension of gestures and results from damage to the left supramarginal or angular gyrus in the parietal lobe and a second type which presents with praxis production problems alone and results from damage that does not involve this parietal region. (See Figure 1-3.)

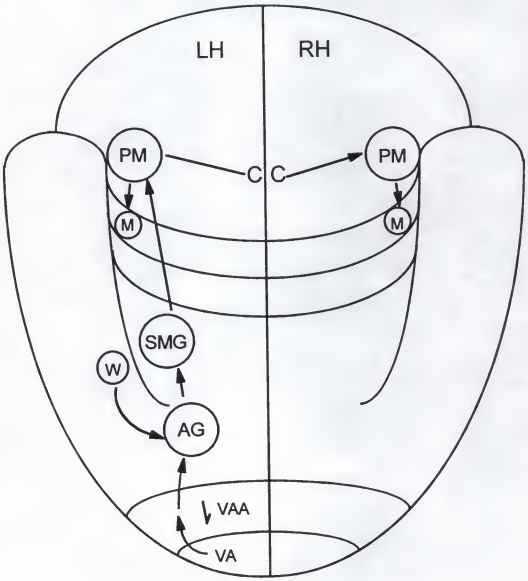


Figure 1-3. Heilman and Rothi's Model of Praxis. View from top of brain. W = Wernicke's area; VA = primary visual area; VAA = visual association area; AG = angular gyrus; SMG = supramarginal gyrus; PM = premotor area (motor association cortex); M = motor cortex; CC = corpus callosum; LH = left hemisphere; RH = right hemisphere. The arrows indicate major connections of the areas shown (from Heilman & Rothi, 1985).

Cognitive Neuropsychological Model of Limb Praxis and Apraxia

Recognizing Liepmann's assertion that skilled praxis was the product of a complex multi-component system and also recognizing that numerous cases were described in the literature that reflected behavioral fractionation of praxis related behavior, Rothi, Ochipa, and Heilman (1991, 1997) proposed a cognitive neuro-psychological model of apraxia in an attempt to capture these dissociations. A schematic representation of this model can be found in Figure 1-4. In this model, the term "action-lexicon" is used as the gestural equivalent to the term "lexicon" used in language which distinguishes that part of the language system which gives a processing advantage for words that the person has previously experienced (Rothi & Heilman, 1985). Therefore, the action-lexicon was defined as that part of the praxis system which gives a processing advantage for movements that the person has previously produced (Rothi *et al.,* 1991, 1997). That is, it is an action memory. The action lexicon was divided into input and output components to account for patients who demonstrate spared gesture comprehension with impaired imitation and gesture to command. The authors stated that for these patients, spoken language gains access to the output action lexicon via semantics without being processed by the input action lexicon (Figure 1-5). In contrast, deficits in gesturing to command with spared repetition and spared comprehension were explained by dysfunction at or after the output action lexicon while sparing the innervatory patterns (Rothi *et al.* 1991).

DeRenzi, Faglioni, and Sorgato (1982) and Rothi, Mack, and Heilman (1986) discussed cases that provide evidence for modality-specific apraxic deficits. That is, the praxis performance of the reported patients differed as a result of input modality

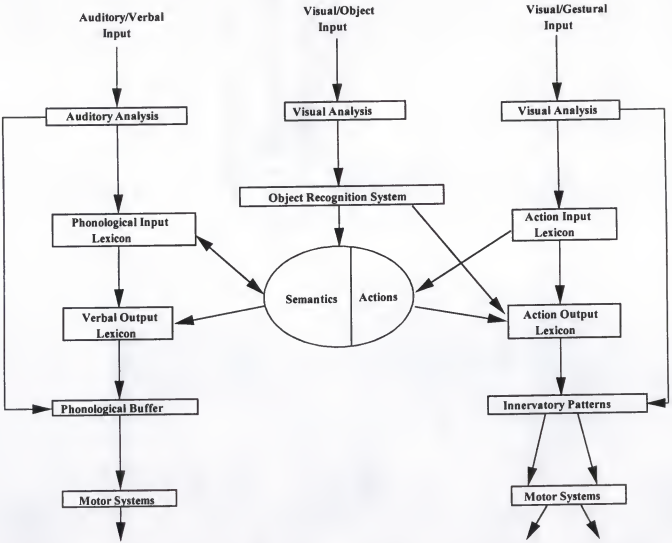


Figure 1-4. Cognitive Neuropsychological Model of Apraxia (from Rothi, Ochipa, & Heilman, 1991).

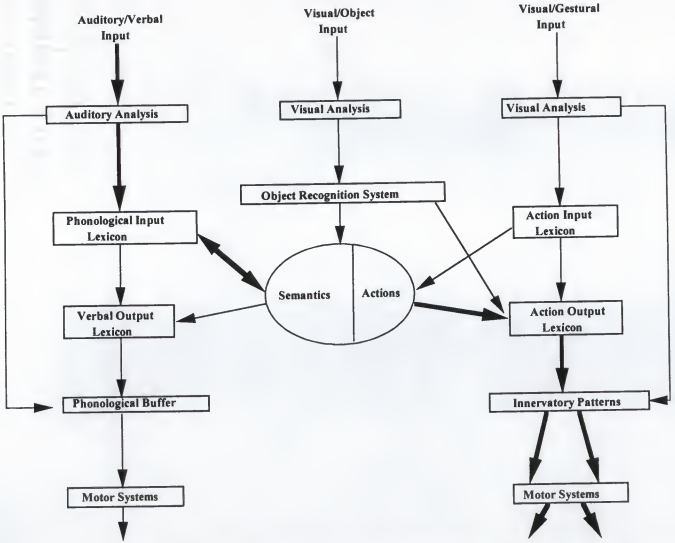


Figure 1-5. Delineation of Gesture to Command Pathway (from Rothi, Ochipa, & Heilman, 1991).

(*e.g.* auditory, tactile, or visual). Rothi *et al.* (1991, 1997) accounted for the differences in performance as a result of input modality by incorporating separate input systems for visually presented gestural information, tactily presented (no visual input), and auditorily presented verbal information. For visual/gestural information, the product of visual analyses accesses either the input action lexicon or the innervatory patterns directly (Figure 1-4). The presence of this direct route from visual analysis to innervatory patterns may account for those patients who can imitate gestures but can not discriminate or comprehend gestures (Rothi *et al.,* 1986). That is, in cases where gesture imitation is not possible through input to output lexicons or input lexicon to semantics to output lexicon, gesture imitation may occur through a "non-lexical" route similar to the route in which nonwords are imitated in language. For visual/ object information, visual analyses activate the object recognition system which produces a structural description of the viewed object. It is hypothesized that the structural descriptions then access either the semantic system or action output lexicon. The connection between the visual analyses and the action output lexicon may allow for the production of gesture from the visual modality without accessing semantics. Visual object information being processed accesses the action output lexicon without prior processing by the action input lexicon because the action output lexicon pertains to codes of the "to-be-performed" actions while the action input lexicon pertains to codes of "perceived" actions (Rothi *et al.*, 1997). This route (visual analysis to action output lexicon) may account for the ability of certain patients who can not comprehend the meaning of the gestures because of a failure of the action semantic system, but can accurately produce gestures to shown tools. These patients may have intact

comprehension of objects but impaired comprehension of actions thereby suggesting a dissociation within the semantic system for information about objects and information about actions. Auditory/verbal input is transmitted to auditory association areas that perform auditory analyses and activate the phonological input lexicon. Information processed by the action input lexicon can be analyzed semantically by the semantic system or phonologically for output by the verbal output lexicon. In figure 1-4, the line connecting the region where auditory analysis is performed to the phonological buffer may be the route that accounts for those patients who can repeat but not comprehend verbal information (Rothi *et al.*, 1991).

Roy and Square (1985) propose that praxis processing involves not only information about gestural production but conceptual information as well. Within the Rothi *et al.*, (1991, 1997) model, conceptual analysis of praxis is accomplished by the action semantic component. Roy and Square (1985) and Raymer and Ochipa (1997) describe praxis conceptual knowledge as knowledge of the functions of tools and objects, knowledge of actions not related to tools and objects, and knowledge of combining actions into sequences. Rothi *et al.*, (1991, 1997) state that actions depend upon the interaction between the conceptual knowledge described above and the sensorimotor information contained in the motor programs. The action semantic system contains the conceptual knowledge relating to tools, objects, and actions. In figure 1-4, the line in the semantics area accommodates recent information that action semantics can be compartmentalized from nonaction semantics. Support for this separation within semantics is found in reports of patients with optic apraxia who were able to accurately gesture to command but were unable to accurately imitate the same

gestures or gesture to visually presented tools (Raymer, Greenwald, Richardson, Rothi, & Heilman, 1992) as well as studies of Alzheimer's patients with impaired action semantics with spared nonaction semantics and vice versa (Ochipa *et al.*, 1992, Raymer, 1992). This separation also accommodates those researchers who claim that there are multiple semantic systems which reflect the modality and nature of input material (Beauvois & Saillant, 1985; Paivio, 1986; Shallice, 1987, 1988).

By comparing patients' performance across tasks, researchers and clinicians may use this neuropsychological model to ascertain the nature of the processing damage and make predictions regarding performance. For example, when gesturing to command, patients would receive auditory/verbal information (*e.g.* "show me how to use a hammer") which would be processed phonologically by the phonological input lexicon followed by the conceptual analysis of the action semantic system. After semantic analysis, the information would be processed by the action output lexicon and the relevant innervatory patterns would be accessed for production of the gesture by the motor system (Figure 1-5). When gesturing to a visually presented tool/object, patients would visually analyze the tool/object and corresponding information would be utilized by the object recognition system with subsequent access to semantics, action output lexicon, and the innervatory patterns for production by the motor system (Figure 1-6). According to the model in Figure 1-6, patients must access semantics to gesture to command correctly but do not have to access semantics to gesture to a visually presented tool/object. Therefore, by comparing the patient's performance in these two tasks, researchers and clinicians may be able to evaluate the integrity of the semantic system.

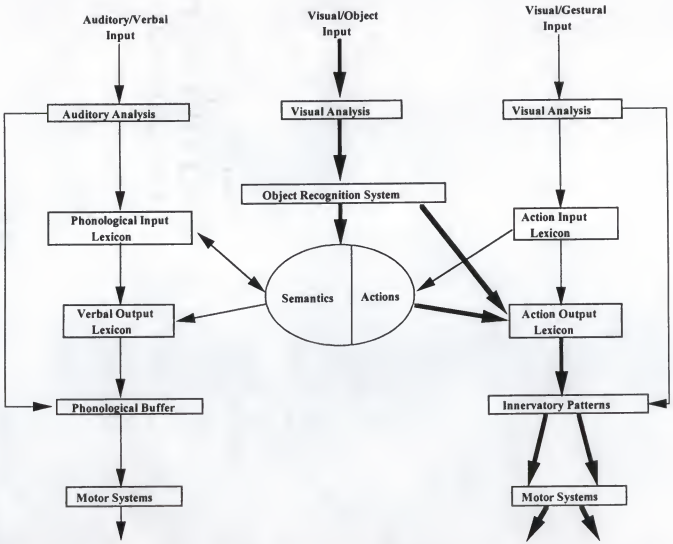


Figure 1-6. Delineation of Gesture to Visually Presented Object Pathway (from Rothi, Ochipa, & Heilman, 1991).

Right Hemisphere Contributions to Praxis

In addition to his proposals that the left hemisphere was dominant for learned, skilled movement, Liepmann also acknowledged that the right hemisphere may also have the ability to plan and generate skilled movement (Liepmann, 1905a/1980a, 1907/1980c, 1920).

However, Liepmann considered the right hemisphere to be subordinate to the dominate left hemisphere and would require the activation of the movement formulae (visuokinesthetic engrams) of the left hemisphere for correct production of skilled movement in situations where the movements were done without manipulation of the actual tool and object. That is, the right hemisphere depends on the integrity of the left praxis system for production of learned, skilled movement in the absence of visual or tactile information. In other words, the right hemisphere relies on the intact left praxis system to produce correct actions when tools and objects are not used (Liepmann, 1905a/1980a, 1920; Maher, 1995).

This ability of the right hemisphere to produce correct movements and actions in context with actual tools and objects was confirmed by Rapcsak, Ochipa, Beeson, and Rubens (1993) who reported a patient, G.K., who suffered destruction of the entire left hemisphere following a massive stroke. G.K. was strongly right-handed and it could be hypothesized that the left hemisphere was dominate for language and praxis. However, results of complete and intensive praxis testing which evaluated each input and output modality for production and comprehension of learned, skilled movement indicated that G.K. was severely impaired in all praxis tasks when actual tools and/or objects were not used. In fact, G.K. reported no difficulty performing common

everyday tasks such as preparing meals and fixing household items in which tools and objects are used together and in the relevant context.

Maher (1995) studied the role of the right hemisphere in production of learned, skilled movements by evaluating the temporal and spatial aspects of gestures produced by patients with left or right hemisphere brain lesions and matched normal control subjects using a scoring system described by Rothi, Mack, Verfaellie, Brown, and Heilman (1988). The subjects produced gestures to auditory command using the arm and hand ipsilateral to the side of lesion to control for possible effects of hemiparesis. The gestures were scored by two independent raters who were blind to the nature of the study. The raters received intensive training before each scoring session which resulted in high inter- and intra-rater reliability. The raters first scored the gestures pass/fail according to correctness. Then, if a gesture was scored as incorrect, error type(s) were awarded based on the above error classification system which included the following error types: internal configuration, external configuration, occurrence, amplitude, movement, and sequencing of movements (*e.g.*, to use a key one must insert, turn, and remove the key in that order). Results of the study showed that the left brain lesioned subjects performed significantly worse than both the right brain lesioned subjects and normal control subjects overall. When frequency of each error type was compared across groups, there were significant differences for all error types except movement and amplitude. Pairwise comparisons were then performed to distinguish etiology of the differences. These comparisons suggested that the significant difference between the left and right brain lesioned subjects for movement errors can be accounted for by extremely poor performance by the left brain lesioned subjects when compared to the

other subject groups. This was a significant result because it supports the notion that the left hemisphere is dominate for praxis. Apraxia is inherently a disorder of learned, skilled movement and significant difficulty in the movement aspects of skilled movements should be observed following damage to this system. The pairwise comparisons also suggested that the significant difference for amplitude apects of movement occurred between the right brain lesioned subjects and the normal controls with no significant difference between the right and left brain lesioned groups. Maher (1995) proposed that this result suggests that both the right and left hemispheres could code spatial aspects of movement.

The Ecology of Apraxia

Significance to clinicians and patients

Other than its lateralizing value, apraxia has not been considered of significant practical importance. DeRenzi (1985) said that apraxia rarely appears in everyday situations and only emerges "out of context as a purposeful response to an artificial request" (page 134.) Because ideomotor apraxia was considered to be an examination-bound symptom that would not attract a clinician's attention unless the clinician specifically looked for it, apraxia may have been overlooked and underestimated in brain damaged patients (DeRenzi, 1985).

Many clinicians might agree that patients do not spontaneously complain of apraxic disturbances (Heilman & Rothi, 1985). One possible explanation for this is that apraxic patients may have anosognosia (unawareness of the disorder) for their praxis difficulties (Rothi *et al.*, 1986). Another possible explanation is that patients with apraxia frequently have a co-occurring right hemiparesis. Therefore, patients may

associate their clumsiness to use of the non-dominant left hand for tasks in which they previously used their dominant right hand. While apraxia may be present, praxis performance may improve when manipulating actual objects or tools (Geschwind, 1965) and caretakers or family members, who rarely have the opportunity to observe tool/object use pantomime, may not be aware of the disorder. In fact, many family members may provide assistance in self-care skills such as feeding and dressing for convenience and efficiency purposes (Heinemann, Roth, Ciehowski, & Betts, 1987).

In a hospital or rehabilitation center, it is possible that the environment of the patients may be controlled and geared toward partial functional independence where a patient can complete at least part of a task independently. For example, in a nursing home environment it has been observed that when it is time for a patient to brush his/her teeth, the nurse may put the toothpaste on the toothbrush, hand the toothbrush to the patient, and tell the patient to "brush your teeth." It has also been observed that during mealtime, the nurse may prepare the food for the patient by cutting the meat, putting the straw in the drink and/or handing the correct utensil to the patient. A study by Heinemann and colleagues (1987), which examined functional outcome of stroke rehabilitation programs, found that all of the independence gained during rehabilitation in the area of feeding was lost by three months after discharge. They proposed that loss of a controlled environment that promoted functional independence (*e.g.*, the caregiver no longer prepared the environment to maximize the patient's skills, but began to assist the patient directly) may explain this decline in function.

Another study examined factors that influenced a person's ability to return to work after a stroke (Saeki, Ogata, Okubo, Takahashi, & Hoshuyama, 1993). The

authors followed 244 patients, ages 24 to 65, who were actively employed at the time of their strokes and extracted information from the admission medical records of each patient. Results indicated that 58% of the patients returned to work by the time of the follow-up which varied from 8 to 77 months post-stroke. The most important factor that determined a patient's ability to return to work was severity of muscle weakness on admission. The second most important factor was presence of apraxia. The odds of a patient without apraxia returning to work were determined to be four to five times greater than for patients with apraxia (Saeki *et al.*, 1993). However, possible limitations of this study are that the authors combined ideomotor apraxia with ideational apraxia, dressing apraxia, and constructional apraxia in the analyses; none of which were operationally defined. As a result, it can not be determined which one or more types of apraxia affected the patients' ability to return to work or whether the authors' definition of apraxia was similar to or different from previously published definitions.

Apraxia in natural contexts

The first study to document the effects of apraxia in the non-clinical environment was conducted by Sundet, Finset, and Reinvang (1988). These researchers investigated variables that affected a patient's ability to function in the home environment following discharge from a rehabilitation hospital. They sent questionnaires to 68 left hemisphere stroke patients and 77 right hemisphere stroke patients six months after discharge from rehabilitation. The questionnaire focused upon activities of daily living and the amount of "dependency" the patients displayed in the home environment. Dependency was defined as the increased need for caregiver

assistance in performing tasks of daily living. The patients were asked 13 simply written yes/no questions such as "requires use of kitchen aids" and "requires help to dress" (Sundet *et al.*, 1988, p.369). Caretakers were asked to answer the questions in the event that a patient could not. Sundet and colleagues compared the relationship between results of the questionnaire (measure of dependency) and neuropsychological deficits such as hemiplegia, aphasia, nonverbal memory deficits, neglect, and apraxia; the presence of which were determined by review of each patients' medical records. Results of the study indicated that the highest predictor of dependency for the left hemisphere damaged subjects was the presence of apraxia.

Limitations of the Sundet *et al.* (1988) study include the authors' reliance upon a questionnaire filled out by caregivers rather than direct patient observation to determine the patients' ability to function independently in a natural environment and context. There was also a six month hiatus between the neuropsychological testing and determination of the patients' "dependency" during which time the patients' performance on the neuropsychological tests (and, in turn, the presence of neuropsychological deficits including apraxia they were reported to document) may have changed. Although a study by Rothi and Heilman (1985) documented that over 80% of patients who are acutely apraxic remain apraxic six months later, it is unknown how many of the 68 left hemisphere damaged subjects in the Sundet *et al.* (1988) study would have been considered apraxic at the time of dependency determination.

One study in which patients were directly observed and which did not have a hiatus between clinical examination and experimental procedures was conducted by Foundas, Macauley, Raymer, Maher, Rothi, and Heilman (1995). Foundas and

coworkers (1995) examined actual tool use during mealtime in 10 left hemisphere stroke patients and 10 neurologically normal controls matched for handedness, age, gender, and education. Subjects were tested for presence of aphasia and apraxia and then, on the same day as testing or no more than three days later, were videotaped while eating a meal. For each subject the meal tray was placed on a table in front of the subject and foil items such as a toothbrush, comb, and pen were included on the tray in addition to the standard tools and utensils for eating (spoon, fork, knife, napkin, and condiments). The location of the standard tools and the foils were counterbalanced to control for their left to right placement on the tray. The examiner left the room and no assistance was given to the subject in preparing or eating the food.

Results of the Foundas *et al.* (1995) study documented two main differences between the control and experimental subjects. The first difference became apparent when the stages of eating (preparatory, eating, and clean-up) were compared across groups. During the preparatory phase, behaviors included such things as opening condiment packages, placing the napkin on the lap, cutting the meat, and putting sugar in the tea. During the eating phase, the food was eaten. During the clean-up phase, behaviors such as putting the napkin back on the tray, putting the utensils on the plate, and pushing the tray away were accomplished. The first difference between the groups was that 80% of the control subjects proceeded through all three phases of the meal compared to only 20% of the experimental subjects. The authors reported that the control subjects respected the boundaries of each phase whereas the experimental subjects did not. That is, the control subjects showed clear, distinct beginning and end points of each phase while the experimental subjects tended to have preparatory, eating,

and clean-up actions interspersed randomly throughout the meal as if there was a lack of anticipation for pending task demands. The authors also reported that within the eating phase, the control subjects ate using eating patterns that were idiosyncratic within subjects but consistently developed across subjects. For example, a control subject might eat portions of the main course (*e.g.*, meat) followed by the bread, the vegetables, and drink of tea and repeat this pattern over again until all food had been eaten. In contrast, the experimental subjects tended to eat in a more random fashion with no definable eating pattern.

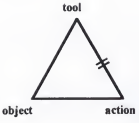
In the Foundas *et al.* (1995) study, the experimental subjects produced more "tool errors" (errors of action in using tools such as spoon, and fork) than "nontool errors" (errors of actions that do not involve tools such as wiping the face or moving the glass) while the control subjects did not produce any errors. One might suggest, however, that because the experimental subjects had a hemiparesis and the comparison group did not, the differences between the groups may be related to the presence of a primary motor defect in the apraxic group. However, an underlying motor system deficit could not explain the difference in eating praxis performance in these two groups because a motor deficit should have affected both tool and nontool actions equally, and it did not. Therefore, even though the experimental subjects had a right hemiparesis, the action errors they produced, selective only for praxis related to tool use, were not the result of an underlying motor problem.

Results of the Foundas *et al.* (1995) study indicated that while the overall eating time of the experimental subjects did not differ from the control subjects, the experimental subjects made fewer actions in general, used fewer utensils, and often

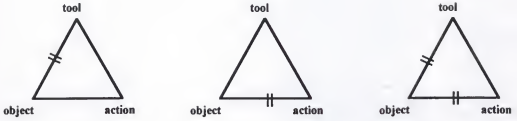
misjudged the advantage of using a tool. The experimental subjects produced significantly more incorrect actions when compared to the controls and as a result were less efficient in executing individual tool actions. Tool misuse and mis-selection errors were produced by all but one experimental subject who happened to score within the normal range on the test for ideomotor apraxia. Errors such as eating ice cream with a fork (mis-selection), cutting with a spoon (misuse), stirring with a knife (misuse), and wiping one's face with a slice of bread (mis-selection) were observed. A schematic representation of misuse and mis-selection errors can be found in Figure 1-7. In contrast, the normal control subjects made more actions in general, used more utensils, and used the utensils correctly throughout the meal. The tool actions of the experimental subjects were often incomplete or imprecise so that a desired goal was not achieved. Foundas*et al.* (1995) argued that the high correlation between number of action errors produced and presence of ideomotor apraxia suggested that ideomotor apraxia caused the production of action errors in this natural context.

A series of studies by Schwartz and colleagues also examined action errors in activities of daily living by brain damaged subjects. The first study by Mayer, Reed, Schwartz, Montgomery, and Palmer (1990) examined a group of brain-injured patients in a rehabilitation hospital. Forty-five patients with traumatic brain injury and six patients with stroke were observed during activities of daily living such as brushing teeth and making coffee. The authors found that 49% of the patients produced errors of action during activities of daily living. Unfortunately, due to the nature of the brain damage of the patients they studied, it is not known whether the action errors were the result of the

Misuse



Mis-selection



Misuse and Mis-selection

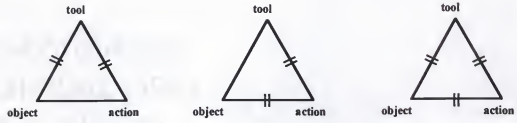


Figure 1-7. Schematic Representation of Misuse and Mis-selection Action Errors. // indicate location of error(s).

general intellectual impairment or executive function defects commonly found in traumatic brain injured patients or of apraxia.

Mayer *et al.* (1990) developed a theory of action based upon Norman and Shallice's (1986) model of attentional control of action which proposes two modes of control of action, one which is automatic and one which requires deliberate attentional control. Mayer *et al.* (1990) studied the action productions within a natural context of 45 patients with closed head injury and proposed that impairment of the deliberate attentional control route was the genesis for production of action errors in their patients with brain damage. For this study, an action coding system was developed that describes the sequence of actions produced by brain damaged patients as either A-1 units (general actions, not task-specific such as rinsing a glass), A-2 units (specific, task-related actions such as unscrewing the cap from a toothpaste container), or crux A-1 units (the action that accomplishes the next goal such as squeezing the toothpaste onto the toothbrush when preparing to brush teeth). The action coding system enabled the researchers to examine which actions were produced out of sequence, were omitted, or were perseverated by applying the action coding system to a script of the patient's actions and examining the relationship and sequence of the A-1, A-2, and crux A-1 units in the patient's production to that of a prototype script.

Mayer *et al.* (1990) then applied the action coding system to a script of actions produced by a brain injured patient during a task of daily living. One patient, H.H., had suffered a bifrontal injury with resulting aphasia and callosal apraxia in which he was apraxic with his non-dominant left hand and not apraxic with his preferred right hand. H.H. was videotaped during breakfast and a script of his actions was written. The

action coding system was applied to the script to analyze action sequences. The authors reported that even though H.H. produced frequent errors such as pouring tomato juice on waffles and attempting to spoon oatmeal into tea, his main deficit was in the efficiency of his action plans. That is, A-1, A-2, and crux A-1 units were produced randomly and not in a logical order or sequence to accomplish the goal of the task at hand. In addition, there was the appearance of action errors that included misuse and mis-selection of tools as well as movement errors that included sequencing and timing of movements. The authors argue that these errors, misuse and mis-selection of tools as well as sequence, were not a result of the patient's apraxia because "in the majority of patients with documented apraxia, there (was) no functional consequence of the apraxic impairment" (Mayer *et al.*, 1990, p.280). Foundas and colleagues, however, would argue that the above statement is not an accurate assumption in that the authors did not test for apraxia and as a result could not speak towards the significance of apraxia to the production of action errors in their patients.

Schwartz, Reed, Montgomery, Palmer, and Mayer (1991) continued their work by applying the action coding system to two specific tasks--making coffee and brushing teeth--as produced by H.H., the brain damaged patient described by Mayer *et al.* (1990). H.H. was videotaped performing these tasks in the natural environment and scripts of his actions were analyzed according to the action coding system described by Mayer, *et al.* (1990). The authors noted that H.H. had a higher susceptibility to object substitutions and object misuse as well as a variability of action errors across time. Regarding normal action processing, the authors argue that learned actions are not

executed as whole programs but are organized into hierarchies of temporally structured units that depend on the prefrontal area of the brain for integration and production.

Based on the results of the study described above, Schwartz *et al.* (1991) proposed four theoretical foundations of intentional actions and action errors: the first tenet claims that intentional action involves activation of an action plan; the second claims that the planning and execution of intentional actions are closely coupled in real time; the third claims that intentional actions are integral to all purposeful behavior; and the fourth claims that errors of action occur due to weakening of the top-down formulation of action plans. This weakening of the action plans allows the patient to be influenced by irrelevant objects and actions leading to a susceptibility of object related errors of action. Schwartz and colleagues (1991) also proposed that the condition of action disorganization observed in brain injured patients while performing activities of daily living be termed frontal apraxia.

The explanation of the mechanism of frontal apraxia offered by Schwartz *et al.* (1991) is not contradictory to Liepmann (1900/1977, 1905a/1980a, 1905b/1980b, 1907/1980c, 1920) and Heilman and Rothi's (1985, 1993) description of movement memories. Rather, Liepmann, Heilman and Rothi's proposals focus upon a retrieval system for the memories of unique learned skilled movements that span from single discreet actions (the action lexicons) to subcomponents (innervatory patterns) of these actions. In contrast, the proposal of Schwartz *et al.* (1991) focuses upon the internal relationship between discreet component actions of larger action goals. Both Liepmann (1920) and Schwartz *et al.* (1991) use the term "frontal apraxia" to describe the movement/action errors that occur when the internal relationship between discreet

action representations in the larger action goal context have been loosened or disorganized by brain damage.

Schwartz, Montgomery, DeSalme, Ochipa, Coslett, and Mayer (1995) expanded the study of action errors by examining J.K., a patient with traumatic brain injury, whose behavior was similar to the patient (H.H.) studied by Mayer *et al.* (1990) and Schwartz *et al.* (1991). J.K. was videotaped while eating breakfast and brushing his teeth and the tapes were scored according to the action coding system described by Mayer *et al.* (1990). J.K. also underwent a battery of neuropsychological tests that included object identification and recognition, conceptual/semantic knowledge, functional/use knowledge, gesture knowledge, gesture production, other language testing, and memory testing. Results indicated that J.K. evinced numerous action errors during the activities of daily living, especially tool misuse errors. The authors postulated that the tool errors were not due to a conceptual/ideational apraxia because J.K. was able to correctly identify tools by name and by function as well as match tools with their corresponding object. However, the authors argued that J.K.'s tool misuse errors were not the result of a weakened top-down processing of action plans found with frontal apraxia because J.K. was able to demonstrate or gesture the appropriate use for a tool from visual and tactile cues, a high level task (Schwartz *et al.*, 1995). The authors concluded that in order to accommodate J.K.'s full range of performance, both a top-down and a bottom-up impairment of intentional action planning should be adopted (Schwartz *et al.*, 1992). That is, the loosening or disorganization of relationships between discreet action representations could be the result of damage to either higher or lower order mechanisms within the action planning and movement production system.

Schwartz *et al.* (1993) adapted the action-trigger-schema (ATS) framework developed by Norman and Shallice (1986) as a means of organizing actions and classifying action errors. The ATS framework proposes that action plans are composed of schemas which are organized memory structures that integrate different types of information for use with actions. These schemas and their interrelations are developed over time through individual experiences and can generate positive or negative activation to specialized systems such as the motor system from the action plans. Familiar action sequences such as eating are represented by groups of schemas organized hierarchically. High level schemas occur in a top-down fashion while the low level schemas occur in an orderly fashion according to the logical progression of actions within the schema. For example, the higher level schema for eating breakfast would be the intent to eat and complete the meal while the lower level schemas would be those actions required to eat the meal such as opening a juice carton, picking up a fork, and taking a bite of food. Using the ATS framework, the authors proposed that action errors are due to the loss or instability of activation within the action schema network possibly due to a weakening of the connections among schemas (Schwartz *et al.*, 1993).

Schwartz *et al.* (1993) argue that a patient with frontal apraxia will produce errors differently during an activity of daily living than a patient with a disorder of attention. Specifically, a frontal apraxic patient with dysfunction in the ability to plan and coordinate action sequences may exhibit incoherence and intrusions of actions which result in a fragmentation of behavior. Patients with frontal apraxia may also use tools and objects in novel or bizarre ways because the action plan for using the tools

and objects is inaccurate, nonspecific, and faulty. In contrast, an attention disordered patient may exhibit intrusions of irrelevant actions and temporary derailments to other tasks resulting in inefficient but coherent action sequences.

Schwartz *et al.* (1993) addressed the issue of whether the observed action errors were related to an ideational apraxia by comparing the action performance of H.H., a traumatic brain injured patient described in Schwartz *et al.* (1991), to the action performance of a left-handed, right hemisphere damaged patient described by Ochipa *et al.* (1989) who displayed ideational (conceptual) apraxia. Although both patients produced numerous errors of action during activities of daily living, H.H. evinced misuse of tools with spared tool function knowledge while the Ochipa *et al.* (1989) patient evinced spared production with impaired tool function knowledge. Schwartz *et al.* (1993) posited that frontal apraxia and ideational apraxia have different underlying mechanisms in that patients with ideational apraxia have impaired conceptual-semantic knowledge while patients with frontal apraxia have spared conceptual-semantic knowledge.

Mayer *et al.* (1990) and Schwartz *et al.* (1991, 1993, 1995) also applied the action coding system to the performances of a subject who suffered a hemorrhagic stroke (J.H., discussed in Schwartz *et al.*, 1991) and a subject who suffered diffuse damage following traumatic brain injury (J.K., discussed in Schwartz *et al.*, 1993, 1995) during two activities of daily living. Although the errors produced by the patients were described, the nature of the patients' brain damage did not allow the researchers to make conclusions about brain-behavior relationships. Both hemorrhagic strokes and traumatic brain injury may be associated with more damage to the brain

than appears on CT/MRI scans. One other limitation of this series of studies is that although it was not their intention to include ideomotor apraxia as a possible factor, ideomotor apraxia is likely to have been present in their cases and may have been an important factor.

Schwartz and Buxbaum (1997) proposed a "Unified Hypothesis" to explain the errors of action observed in patients with frontal and/or ideational apraxia. The author's schematic representation of this hypothesis can be found in Figure 1- 8. The Unified Hypothesis is based upon the ATS framework which states that through experience and learning, higher level schemas organize lower level schemas into temporally ordered sequences. Experience and learning solidify connections between higher and lower level schemas for specific tasks making the retrieval of the lower level schemas automatic. For example, one higher level schema would contain information on the sequence of actions required to eat a meal and would automatically activate lower level schemas for cutting, drinking, wiping, and stirring, etc., as needed throughout the meal process. Another high level schema would contain information on the sequence of actions required to build and would activate lower level schemas for getting the permit, hiring architects, buying materials, putting in the foundation, etc. In turn, the schema for putting in the foundation would activate lower level schema for marking the ground, digging the hole, pouring the concrete, and etc. Whether a schema is considered "low" or "high" is determined by the relationship between schema within the goal of the task. Schwartz and Buxbaum (1997) differentiated between learned, routine actions and novel or nonroutine actions in that pre-existing connections existed between high level and low level schemas for learned, routine actions but not for novel

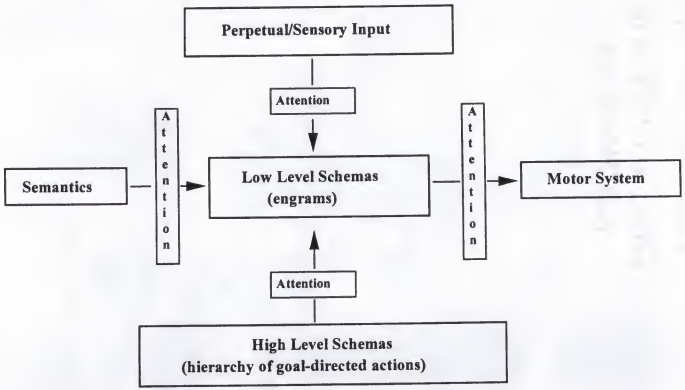


Figure 1-8. Schematic Interpretation of the Unified Hypothesis (from Schwartz & Buxbaum, 1997).

or nonroutine actions. The pre-existing connections between higher and low level schemas allow learned, routine actions to become more automatic, but also more prone to error (Schwartz & Buxbaum, 1997; Reason, 1990). According to Schwartz and Buxbaum, (1997), it is the evocation of attentional factors at certain critical points during activation of higher level schemas which opposes error tendencies and keeps the error rate low.

Schwartz and Buxbaum (1997) discussed two key assumptions of the Unified Hypothesis. The first key assumption is that damage to the movement engrams and/or the perceptual systems, or the semantic systems that input to the movement engrams would affect the ATS system by compromising its automatically. This lack of automaticity leads to greater dependence on attention and specifically on supervisory attention. Supervisory attention is evoked when automatic action routines are insufficient or inappropriate to complete the task at hand (Norman & Shallice, 1980, 1986). Supervisory attention has been equated with working memory by Baddeley (1986). Schwartz and Buxbaum (1997) proposed that "for the patient with faulty access to gesture engrams or perceptual-semantic processing, successful performance of familiar, pragmatic action, depends more heavily on [attentional] control processes" (p.19).

The second key assumption of the Unified Hypothesis is that behavioral consequences of this increased dependency on supervisory attention/working memory depend upon a combination of the severity of damage to the ATS system and the status of the supervisory attention/working memory, itself. That is, a deficit in one component (activation of action schemas or attentional control systems) of the Unified

Hypothesis may not impact actions in natural contexts without some degree of damage to the other component. The authors argue that it is this combination of deficits that leads to action errors in natural contexts. That is, patients who have deficits in the automatic activation of action schemas will not evince action errors unless there is also a deficit in supervisory attention/ working memory and/or executive control processes. Conversely, patients with deficits in executive control processes will not evince action errors unless there are co-existing deficits in posterior processing systems which impact the automaticity of the action schemas. In addition, patients with a cortical dementia or diffuse head injury, may demonstrate the most serious errors of action during activities of daily living because of the severity of deficits in both the automatic activation of action schemas as well as executive control systems (Schwartz & Buxbaum, 1997).

The Relationship Between Apraxia and Pragmatic Action

It is possible that neither the model proposed by Rothi *et al.* (1991, 1997) or the Unified Hypothesis proposed by Schwartz and Buxbaum (1997) can independently account for all of the errors produced by brain-damaged patients during goal-directed activities of daily living (pragmatic action). In the following discussion, pragmatic action will be defined as the sequences of movements required to progress toward and obtain a definable goal. The goal may be directed toward common, everyday actions such as eating, or uncommon actions such as building a house (uncommon actions may vary from person to person depending upon life experiences). In contrast, movement is defined as changes in posture, place, or position which can occur within an action as well as independently. Actions and movements have been disambiguated to represent the notion that movements are the inherent motor aspect of performing actions (*i.e.*,

movements are the final common denominator for all actions) and that actions are a series of movements arranged in hierarchically organized schemas according to the end goal. Using these definitions of pragmatic action and movements, the Rothi *et al.* (1991, 1997) Cognitive Neuropsychological Model of Limb Praxis and Apraxia encompasses aspects related to the planning, organization, production and comprehension of discreet movements (hereafter referred to simply as "movements") while the Schwartz and Buxbaum (1997) Unified Hypothesis covers aspects related to the planning, organization, production, and comprehension of actions which incorporate discreet movements (hereafter referred to simply as "actions") and it is the relationship or interaction between these two theories that is crucial for the understanding of pragmatic action. In the following discussion, a relationship between movements and actions will be proposed which will then be used as a foundation for examining the production of errors during goal-directed activities of daily living.

It is proposed that higher level action schemas discussed by Schwartz and Buxbaum (1997) access lower level schemas of movement organization found in the action output lexicon as discussed by Rothi *et al.* (1991, 1997) (Figure 1-9). The action output lexicon, hereafter referred to as praxicon as suggested by Heilman and Rothi (1997), in turn, accesses the innervatory patterns and the motor system in that order, for production of the movement (Rothi *et al.,* 1991, 1997) (Figure 1-10). Within the high level schemas, information about object, tool, sequence, and other aspects of action are organized hierarchically into plans or scripts according to specific goals. It is also proposed that the high level action schemas also contain attributes of movement planning but under normal circumstances, the praxicon takes precedence.

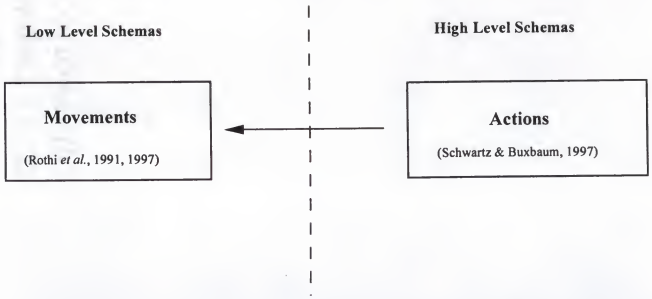


Figure 1-9. Relationship between Actions and Movements.

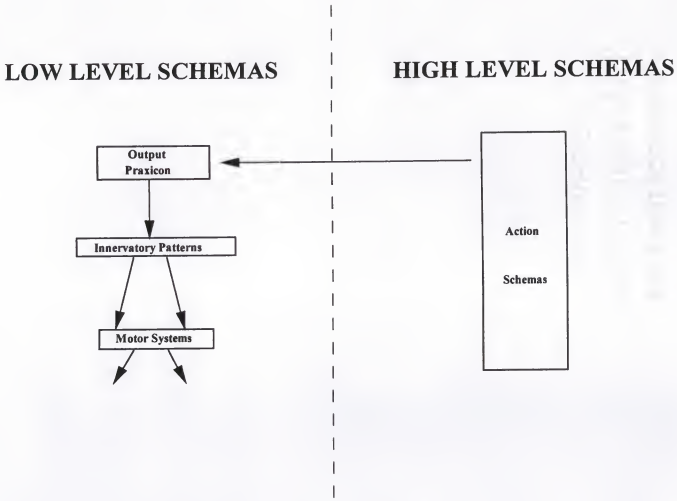


Figure 1-10. Breakdown of Low Level Schemas.

According to Schwartz *et al.* (1991, 1993, 1995, 1997) there may be many different levels of schema. That is, for one set of goal-directed action sequences, a particular schema may be organized as a "lower level schema" whereas in a different set, the same schema may be organized as a "higher level schema." In fact, it is possible that schemas may be organized in such as way that a lower level schema may be included in a higher level schema which is included in an even higher level schema and etc. In order to conceptualize this framework it is proposed that within the high level schematic system, information is stored in a distributed network framework and is therefore subject to assumptions associated with parallel-distributed-processing (PDP) models as described by Rumelhart and McClellan (1986). For example, three assumptions about connections between nodes that are frequently activated together are 1) as the number of times of activation increases, the strength of the connection will also increase, 2) as strength increases the nodes are activated faster, and 3) the stronger the connections, the less likely they are to be degraded (Rumelhart & McClellan, 1986; Nadeau. 1994). The corresponding assumptions for the high level schematic system are 1) stronger associations occur between information/schemas that are frequently activated together, 2) the schemas with the most activation become learned, routine actions and eventually become automatic, and 3) the schemas for common, learned actions are less likely to show deficits following brain damage due to "a great deal of redundancy [interconnectiveness] in the neural systems responsible for pragmatic action" (Schwartz & Buxbaum, 1997, p2).

Norman and Shallice (1980, 1986) and Schwartz and Buxbaum (1997) discussed the role of supervisory attention/working memory (SA/WM) in the

production of actions. The role of SA/WM was to monitor actions and step in as needed during their production so errors would be circumvented. SA/WM also contributed the most resources to monitor novel actions, a lesser amount of resources to monitor non-routine actions, and the least amount of resources to monitor routine or learned actions which could eventually become automatic and be produced correctly without attentional resources (Schwartz & Buxbaum (1997). To account for these different aspects of actions, the connection between executive functions (as defined by Schwartz *et al.*, 1991, 1993, 1995) and the output praxicon has been divided into four routes, each requiring different amounts of attentional resources (Figure 1-11). It is proposed that the route for production of automatic actions (those learned, routine actions that are performed in context using actual tools and objects) bypasses attention and accesses the output praxicon directly because the combined effects of the natural context, tools, and objects may be enough information to activate that part of the motor system specialized for overlearned, automatic movements (Paillard, 1982, Marsden, 1982, Rapscak *et al.*, 1993, Schwartz & Buxbaum, 1997) The routes for routine and non-routine actions both access the output praxicon but non-routine actions require greater attentional resources than routine actions for accurate production. Additionally, the route for novel actions accesses the innervatory patterns rather than the output praxicon because by definition, "novel" movements have not been produced previously and, therefore, would not have engrams represented in the output praxicon. Novel actions also require more attentional resources than either routine or non-routine actions.

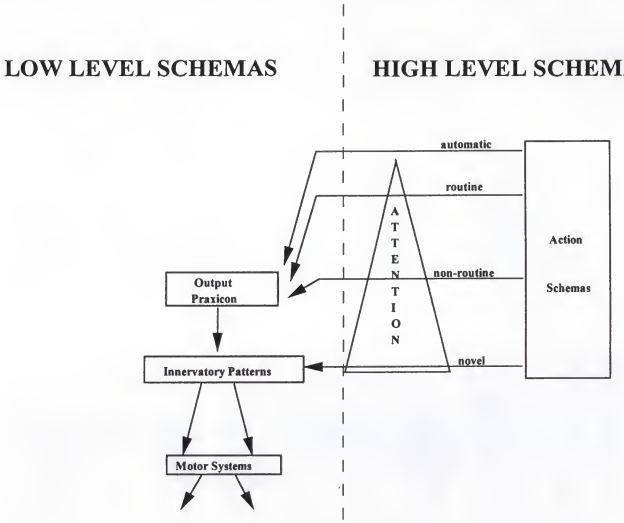


Figure 1-11. Breakdown of High Level Schemas.

Because the output praxicon receives information from the semantic system and the semantic system is accessed by the perceptual systems, both systems (semantic and perceptual) have been added to the model according to Rothi *et al.,* (1991, 1997) in Figure 1-12 and 1-13. Additionally, it is proposed that the executive functions in the high level schematic system also communicates with the semantic system in order to establish semantic relationships and interactions among related schemas. To accommodate this communication, the semantic system has been divided into two parts with one part connecting to the output praxicon and another part with connections to and from executive functions. This division is not without debate, however, because one could argue that the semantic system which communicates with the low level movement schemas contains procedural information about tools and objects while the semantic system which communicates with the high level action schemas contains episodic information about action sequences.

Schwartz and Buxbaum (1997) and Reason (1979, 1984) also discussed visual, auditory, and tactile perceptual systems as important input systems for online monitoring and feedback to ensure correct action production. To accommodate these reports, the perceptual system has been added to the high level action schema system with input connections to executive functions (the planning and organization of action schemas) and attention (Supervisory attention/working memory) in Figure 1-14. The perceptual systems, therefore, send information to both the low (movement) and high (action) schema systems.

In summary, the proposed relationship between apraxia and pragmatic action described above separated the components of pragmatic action into low and high level

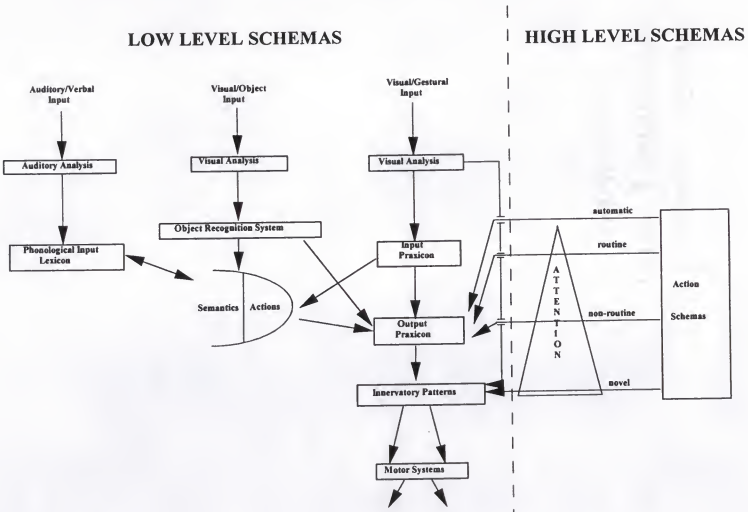


Figure 1-12. Addition of Perceptual Input to Low Level Schemas (Rothi *et al.*, 1991, 1997).

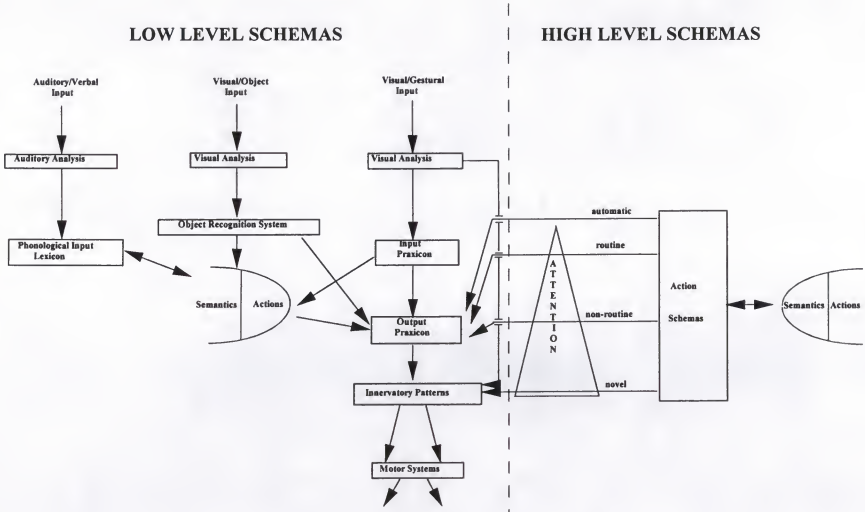


Figure 1-13. Addition of Semantic System to High Level Schemas.

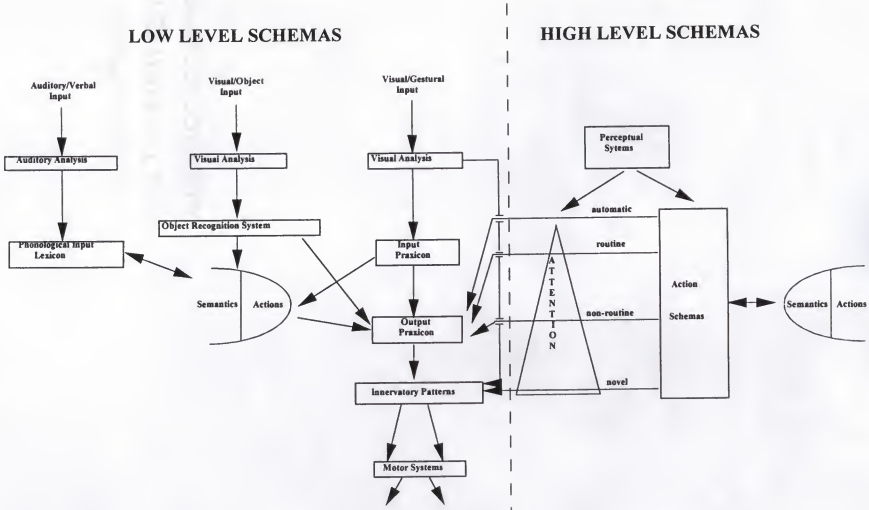


Figure 1-14. Proposed Relationship Between Apraxia and Pragmatic Action.

schematic systems. The low level system targets planning, organization, production, and comprehension of movement and movement sequences which are the final common denominator of actions. The high level system includes planning, organization, production, and comprehension of actions and action sequences (schemas) which originate in the complex schematic system of executive functions and require attentional monitoring for correct production. The final common denominator for both actions and movements is the praxis system, specifically, the output praxicon, innervatory patterns, and motor system.

Predictions of the Proposed Relationship Between Movements and Actions

Based on the above description of the relationship between action schemas and movements, the following predictions are made. First, pragmatic action can be divided into two levels, a high level for actions and a low level for movements, with the final common denominator of production through the output praxicon. Following this prediction, there should be dissociations between the ability to plan and organize actions (which occurs at the high level) from the ability to plan and organize movements (at the low level). A deficit in the ability to plan, organize, and execute actions has been documented by Mayer *et al.* (1990), Schwartz *et al.* (1991, 1993, 1995), and Schwartz and Buxbaum (1997) who studied patients with generalized brain damage from closed head injury and labeled the deficit frontal apraxia, and Sirigu, Zalla, Pillon, Grafman, Agid, and Dubois (1995, 1996), and Sirigu, Zalla, Pillon, Grafman, Dubois, and Agid (1996) who studied patients with frontal lobe damage and labeled the deficits as problems in managerial knowledge. However, Mayer *et al.* (1990), Schwartz *et al.* (1991, 1993, 1995), Schwartz and Buxbaum (1997) and Sirigu

et al. (1995, 1996, in press) did not test for apraxia, a deficit in the ability to plan, organize and execute movements. Ideomotor apraxia is well documented in the literature by Liepmann (1900/1977, 1905b/1980b, 1907/1980c, 1920), DeRenzi (1985), DeRenzi *et al.* (1966, 1982), Heilman *et al.* (1982), Rothi *et al.* (1985), Rothi and Heilman, (1985), Sirigu, Cohen, Duhamel, Pillon, Dubois, and Agid (1995), and Foundas *et al.* (1995). Ideomotor apraxia has been localized to damage in the dominant hemisphere (Liepmann & Maas, 1907; Geschwind, 1965; Heilman, 1979; and Poizner, Meriens, Clark, Macauley, Rothi, & Heilman, 1997) and specifically to posterior parietal cortex (Heilman, 1979; Freund, 1991; and Poizner *et al.*, 1997). However, the focus of the above studies was on either high level action planning and organization abilities, without documenting presence or absence of low level factors, or vice versa--focus on low level action planning and organization abilities without documenting presence or absence of high level factors.

Only one study to date has examined both low and high level schematic functions within the same patient. Schwartz *et al.* (1995) examined action planning and praxis in a patient, J.K., who suffered brain damage as the result of closed head injury. Results indicated that J.K. evinced significant deficits in both the planning and organization of actions and the planning and organization of movements. Unfortunately, due to the extent of brain damage (lesions in right frontal lobe, bilateral temporo-parietal lobe, and left occipital lobe) brain-behavior relationships could not be made. Further studies are needed to document whether patients with impaired planning and organization of actions have spared planning and organization of movements and vise versa. However, because the supplementary motor area (SMA)

located in the prefrontal gyrus has been implicated in the production of learned movements (Heilman, 1979) and it is proposed that the production of movements is the final common pathway for all actions, researchers must be strict as to location of lesion (*i.e.*, with/without damage to SMA in patients with frontal lobe lesions) and in modality of task (*i.e.*, test action planning and organization through pictures and not through actual production for patients with ideomotor apraxia as the ideomotor apraxia will affect production) when selecting subjects and experimental tasks. It should also be noted that due to the proposal that the output praxicon is the final common pathway for production of actions, patients with ideomotor apraxia have the potential to be impaired in production across tasks - clinical and environmental. This impairment across tasks has been documented experimentally by Foundas *et al.* (1995) and through case reports by Jacobs, Macauley, Adair, Gold, Rothi, and Heilman (1995) and Sirigu *et al.* (1995).

A second prediction states that deficits in action semantics should affect the functional use of tools within higher level schemas (in context or part of a goal-directed schema) as well as within lower level schemas (out of context or independent of goal-directed schema). Ochipa *et al.* (1989) reported a left-handed patient with a right hemisphere lesion who demonstrated deficits in the functional use of tools across high and low level tasks. High level tasks included eating a meal and low level tasks included pantomiming to command (*e.g.,* show me how you use scissors). Results indicated that the patient was impaired in all tasks in which the functional relationship between tool and object were important. It should be noted, however, that Ochipa *et al.* (1989) labeled the patient's disorder "ideational apraxia" and defined it as a loss of conceptual knowledge related to tool use. Raymer (1992) and Raymer and Ochipa

(1997), labeled this disorder "conceptual apraxia" which better describes this global impairment of both low and high level schema functions.

A third prediction states that errors of action produced by non brain-damaged people should relate to high level schema problems, the planning and organization of actions, and not low level schema problems, the planning and organization of movements. "Normal" people have intact praxis systems and should therefore produce skilled movements accurately. However, the correct production of actions depends upon the mediation of supervisory attention/working memory and if a person is not "paying enough attention" or becomes distracted during the task at hand, a different action, correctly produced, may be performed. Reason (1979, 1984, 1990) and Reason and Mycielska (1982) studied human error and lapses of attention in everyday life. They report that normal people produce errors of omission, addition, anticipation, perseveration, capture, exchange, and substitution all of which occur within action schemas and not within movements. For example, an error of capture occurred when a lady went to the bathroom intending to brush her hair but she picked up the toothbrush and began to brush her teeth. This lady did not pick up the toothbrush and brush her hair or perform any action out of sequence for that particular schema, she merely performed the wrong action schema for her intention which is a high level schematic system error. Schwartz and Buxbaum (1997) classified the errors produced by brain damaged patients during six daily activities, including making toast and wrapping a present, using Reason's (1979, 1984) classification system. Schwartz and Buxbaum (1997) reported that the brain damaged patients produced errors not only from the categories described by Reason (1979, 1984) but also in four categories not described

by Reason (1979, 1984) - grasp/spatial misorientation, spatial misestimation, tool omission, and quality of movement. These four error types are hypothetically related to the low level schematic system and would be predicted in patients with damage to the praxis system by this model. Unfortunately, Schwartz and Buxbaum's (1997) patients had heterogeneous etiologies and were not tested for conceptual or ideomotor apraxia and therefore, direct evidence to support this prediction can not be obtained. Further studies are necessary to examine the types of errors produced by brain damaged patients and to establish a classification system using the framework of the proposed model.

Classification of Action Errors

The types of errors described by Foundas *et al.*(1995), Ochipa *et al.*(1989), Mayer *et al.*(1990), Schwartz *et al.* (1991, 1993, 1995), Sirigu *et al.* (1995, 1996) and Schwartz and Buxbaum (1997) can be divided into two categories based upon the low (movement) and high (action) schema systems proposed by the relationship described above (Figure 1-14). That is, error types that reflect deficits in the praxis production systems (Rothi *et al.*, 1991) would make up low level schematic system errors while error types that reflect deficits in the planning and organization of action in the executive function and attentional control mechanisms (Schwartz & Buxbaum, 1997) would make up high level schematic errors. However, some types of errors could be produced by both a high and a low level schema deficit. For example, the misuse of a fork to stir tea could be explained by a deficit in the praxis conceptual system - a low level schema error - or by a deficit in attentional control of the action sequences (the patient had just finished using a fork to eat meat and did not switch tools before stirring

tea) - a high level schema error. Other types of errors such as the body part as tool errors reported by Rothi *et al.* (1991) can only be explained by a low level schema deficit.

However, no study to date has measured deficits associated with low and high level schemas within the same group of patients in order to tease out which action errors are associated with which type of deficit. Foundas *et al.* (1995) and Ochipa *et al.* (1989) tested the praxis production and conceptual systems (low level schema) while Mayer *et al.*, (1990), Schwartz *et al.*, (1991, 1993), Sirigu *et al.* (1995, 1997), and Schwartz and Buxbaum (1997) tested executive function, managerial knowledge, and planning/ organizational abilities (higher level schema). Schwartz *et al.*, (1995) measured both low and high level schema abilities in a patient with diffuse brain damage after closed head injury. However, an MRI of this patient showed focal lesions in the left occipito-parietal area, right frontal area, and bilateral temporal areas which negated any attempt to establish brain-behavior relationships and examine the underlying nature of action errors.

Foundas *et al.* (1995) proposed that the errors produced by the experimental subjects in their study could be divided into two groups - production and conceptual. Production errors consisted of movement, timing, and sequence errors and conceptual errors consisted of misuse and mis-selection of a tool for the intended task. However, as discussed above, production and conceptual errors can occur as the result of deficits in low and/or high level schema systems. Production errors have been associated with ideomotor apraxia resulting from discrete lesions of the dominant left hemisphere (Foundas *et al.*, 1995) as well as executive function disorders from closed head injury

(Schwartz *et al.*, 1995) and conceptual errors have been associated with ideational/ conceptual apraxia resulting from discrete lesions of the dominant hemisphere (Ochipa *et al.*, 1989) as well as resulting from generalized brain damage from closed head injury (Schwartz *et al.*, 1995). However, all of the experimental subjects in the Foundas *et al.*, (1995) study had unilateral (dominant hemisphere) brain lesions resulting from single strokes. Even though it would be easy to propose that the errors produced by these subjects originated in the low level schema system, these subjects also evinced deficits in the overall organization of meal planning, a high level schema system. However, Foundas *et al.* (1995) did not test for presence of conceptual apraxia or executive function (planning/ organizational) deficits that may explain the presence of high level schema errors. Therefore, although Foundas *et al.* (1995) argued that the errors produced by the experimental subjects strongly correlated with ideomotor apraxia, it is not known whether conceptual or executive disorders also influenced the production of action errors within these subjects.

Each of the above studies (Foundas *et al.*, 1995; Ochipa *et al.*, 1989; Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Sirigu *et al.* 1995, 1996, in press; and Schwartz & Buxbaum, 1997) documents the presence of action errors in activities of daily living. However, each study evaluated subjects with different etiologies of brain damage (*i.e.*, traumatic brain injury versus stroke) using different evaluation criteria and asking different research hypotheses as to the nature of these action errors. As a result, the nature of the movement and action errors produced by brain damaged patients observed in natural contexts remains unclear. It is possible that by examining deficits associated with both low and high level schemas in a homogeneous group of

subjects within a well controlled study that the nature of action deficits in activities of daily living can be better understood and explained.

Statement of the Problem

While the presence of action and movement errors in natural contexts has been described by several research groups, the mechanism of these action errors has not been determined. In the above discussion, four explanations that may account for these errors in natural contexts were described. The first proposes that movement and action errors in natural contexts may be the result of an executive disorder of planning and organization (Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Sirigu *et al.*, 1995, 1996; and Schwartz & Buxbaum, 1997), a high level schematic system function according to the proposed relationship between movements and actions. The second proposal states that action errors in natural contexts may be the result of an impaired supervisory attention/ working memory (Schwartz *et al.*, 1995; Schwartz & Buxbaum, 1997) a high level schematic system function according to the proposed relationship between movements and actions. The third proposal states that action errors in natural contexts may be the result of a deficit in action semantics or tool-function-object knowledge (Ochipa *et al.*, 1989, 1992) a function that implicates both high and low level schematic system function according to the proposed relationship between movements and actions. The fourth proposal states that the action errors in natural contexts may be the result of ideomotor apraxia, an impairment in the production of learned, skilled movements (Foundas *et al.*, 1995); a low level schematic system function according to the proposed relationship between movements and actions.

Previous studies of action errors compared the performance of left brain damaged patients with normal controls (Foundas *et al.*, 1995), compared patients with heterogeneous etiologies with normal controls (Sirigu *et al.* 1995, 1996; Schwartz & Buxbaum, 1997), or were single case studies (Ochipa *et al.*, 1989; Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995). In fact, only three subjects, presented as single case studies, form the basis of the Mayer *et al.*, 1990, and Schwartz *et al.*, 1991, 1993, and 1995 studies. The proposed cognitive neuropsychological model of pragmatic action predicts that action errors can occur as the result of low level schematic system impairment as well as high level schematic system impairment, both of which can be associated with unilateral lesions of the dominant hemisphere. However, no study to date has examined the presence of action errors in patients with unilateral lesions of the nondominant (right) hemisphere in right-handed individuals. Due to the heterogeneous nature of brain damage in previous studies as well as the lack of testing in both the low and high level schema system, conclusions about brain-behavior relationships and the nature of action errors can not be made. Therefore, studies are needed that 1) include subjects with unilateral lesions of the nondominant (right) hemisphere and examine both low and high level schema function; and 2) use a consistent error classification system to score the subjects' performance in natural contexts which incorporates scoring systems described thus far in the literature - by Reason (1979, 1984), Foundas *et al.* (1995), Schwartz *et al.* (1995), and Schwartz & Buxbaum, (1997); and 3) compare subjects with brain damage limited to one hemisphere (right or left) from a single event rather than generalized brain damage resulting from trauma in order to examine brain-behavior relationships more clearly.

The purpose of this study, therefore, is to examine the nature (low versus high level schema system functions) of action errors produced during an activity of daily living in the natural environment in patients with left or right hemisphere brain damage as well as neurologically normal control subjects. The following specific questions will be addressed:

1. Does brain damage in either hemisphere result in production of action errors in the natural environment or are action errors specific to left hemisphere brain damaged patients?

The Foundas *et al.* (1995) study documented production of action errors by ten left hemisphere damaged patients in the natural context of eating a meal. Other studies described action errors produced by single subjects with either right hemisphere damage (in a left-handed patient) or closed head injury (Ochipa *et al.*, 1989; Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; and Schwartz & Buxbaum, 1997). Because only the left hemisphere damaged patients were experimentally studied, it is not known whether the action errors described in the above studies are specific to patients with lesions of the dominant hemisphere or can be found in right hemisphere damaged patients as well. Using the proposed relationship between apraxia and pragmatic action, it is proposed that patients with dominant (left) hemisphere brain damage produce action errors consistent with both low and high level schema system functions while patients with lesions of the nondominant (right) hemisphere produce action errors consistent with high level schema system function only. This difference is due to the bilateral representation of executive functions and the lateralized representation of the visuokinesthetic engrams for learned movement to the left hemisphere. This difference would predict that patients with left hemisphere damage

have more opportunity for errors and may therefore produce more errors than patients with right hemisphere lesions. According to the proposed model, patients with lesions of the nondominant right hemisphere may evince action errors as a result of executive system function impairment (deficits in the planning, and organization of actions) as well as from attention system impairment as these are both represented bilaterally and impairment of one hemisphere may result in deficits in these systems. The errors resulting from attentional system impairment may include spatial errors resulting from neglect which has been described as a disorder of attention by Brain (1941), Zangwill (1944), McFie, Piercy, and Zangwill (1950), Denny-Brown and Banker (1954), Heilman (1979), and Heilman, Watson, and Valenstein (1985). Heilman (1979) reported that some patients with neglect fail to eat from one side of their plate but have spared action plans for eating and use of tools during eating. The null hypothesis of no difference in number of action errors produced while eating a meal between the groups (left hemisphere damaged subjects, right hemisphere damaged subjects, and controls) will be tested.

2a. Does presence of deficits in
1. production of learned skilled movements,
2. conceptual knowledge of tool-function relationships,
3. action planning and organization, and
4. supervisory attention/working memory
predict production of action errors in the natural environment?

2b. And if so, to what extent does each type of deficit (low level system deficits--1 and 2 above and high level system deficits--3 and 4 above) predict type of error (including misuse, mis-selection, external configuration, internal configuration, timing, quantity, sequence [omission, addition, sequence], exchange, substitution, movement, and body part as tool)?

Deficits in conceptual knowledge of tool-function relationships and deficits in production of learned skilled movements are proposed to result from lateralized lesions

to the dominant (left) hemisphere in most right-handed people (Rothi & Heilman, 1985) and are hypothesized to be associated with low level schemas in the proposed relationship between movements and actions. Deficits in the planning and organization of actions and deficits in supervisory attention/working memory are proposed to result from left, right, and bilateral lesions as well as degenerative brain damage (Schwartz *et al.*, 1991, 1993, 1995) and are hypothesized to be associated with high level schemas in the proposed cognitive neuropsychological model of pragmatic action. As a result, all four deficits of higher cortical function described above have the potential to produce action errors in natural contexts. To examine the relationship between these disorders of higher cortical function and production of action errors in the environment, independent measures (non-context dependent) of each disorder will be correlated with total number of action errors produced in the experimental measures (context-dependent). The null hypothesis of no significant correlation between any one independent measure of higher cortical function and number of total action errors produced during the context dependent activities of daily living will be tested.

In addition, it is hypothesized that tool and nontool errors will be produced to different degrees by patients depending on the type and severity of higher cortical function deficit. That is, patients with deficits in the praxis production and conceptual systems (low level movement schema) may produce more tool errors (misuse, mis-selection, internal configuration, external configuration, quantity of food on a utensil, movement associate with the tool, and body part as tool) than patients without a deficit in the praxis production and/or conceptual system. Hypothetically, the number of tool errors produced should reflect the severity of the underlying deficit(s). Patients with a

deficit in the planning and organization of actions and/or supervisory attention/working memory (high level schema) may produce more nontool errors (exchange, substitution, sequence, omission, addition, and timing,) than patients without a deficit in the planning and organization of actions and/or supervisory attention/working memory. Although these patients may also show tool errors of misuse and mis-selection which could arise from high level schema deficits, these patients should not evince tool errors of internal configuration, external configuration, quantity, and body part as tool without a concomitant deficit in the praxis system.

As a result of the action error classification system described above, it is proposed that the errors reported by Foundas *et al.* (1995) as resulting from ideomotor apraxia or production disorders, may also have been influenced to a certain extent by high level schema deficits and that errors reported by Mayer *et al.* (1990), Sirigu *et al.* (1995a, 1995b, 1996), and Schwartz *et al.* (1991, 1993, 1995) as resulting from disorders of action planning and organization and/or supervisory attention/working memory may also have been influenced by production and conceptual disorders. However, it is not known which of the four disorders (praxis production, praxis conceptual, action planning/ organization, and supervisory attention/working memory) is most influential in inducing action errors in natural contexts or if all four disorders are equally influential. To answer this question, independent measures of the praxis production system, praxis conceptual system, action planning/organization, and supervisory attention/working memory will be correlated with frequency of each type and classification of error produced during the experimental activities of daily living.

The null hypothesis of no significant correlation between any one independent measure and number of action errors within one type/classification will be tested.

CHAPTER TWO
METHODS

Some patients with brain damage produce action errors during activities of daily living (Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Schwartz & Buxbaum, 1997; Ochipa *et al.*, 1989; Foundas *et al.*, 1995). Investigators in recent research reports have examined the planning, organization, and production of these action errors through different theoretical models with different inherent assumptions and predictions, using different research hypotheses and evaluation criteria, and included subjects with heterogeneous etiologies of brain damage (Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Schwartz & Buxbaum, 1997; Sirigu *et al.*, 1995, 1995, 1996, in press; Ochipa *et al.*, 1989; Foundas *et al.*, 1995). The current study describes a proposed relationship between apraxia and pragmatic action which serves as a framework for the examination of the nature of movement and action errors produced by patients with unilateral left or right hemisphere brain damage as well as matched normal control subjects.

Subjects

Three subject groups (two experimental groups and one control group) participated in this study. The first experimental group consisted of patients with left hemisphere strokes (LBD) and the second experimental group consisted of patients with right hemisphere strokes (RBD). All experimental subjects were at least one month post onset of their stroke, were right-handed, and native English speakers. None had a history

of previous neurological disease. The experimental subjects were at least one month post onset of a unilateral CVA (from a single event) as documented by CT/MRI scan and were identified and recruited through the following sources: Veterans Affairs Medical Center, W. A. Shands Teaching Hospital, and UpReach Rehabilitation Center, Gainesville, Florida; Sacred Heart Medical Center, Deaconess Medical Center, St. Luke's Rehabilitation Center, and University Programs in Communication Disorders Speech and Hearing Clinic, Spokane, Washington. CT/MRI studies done at least two weeks post-stroke were obtained for each experimental subject and reviewed by a neurologist. The neurologist classified the lesions as either right or left as defined by relationship of lesion to longitudinal fissure. The lesion locations were used to classify the experimental subjects into left-hemisphere or right-hemisphere damaged groups.

The LBD experimental group included 20 subjects whose ages ranged from 32 to 79 (M = 60.2; SD = 13.50). Educational level ranged from 3 to 16 years (M = 11.85; SD = 3.25). Time post stroke varied from one month to 261 months (M = 41.45; SD = 65.28). Descriptive information for these LBD subjects is provided in Table 2-1.

The RBD experimental group included 10 subjects whose ages ranged from 54 to 77 (M = 64.2; SD = 8.11). Educational level ranged from 8 to 16 years (M = 12.60; SD = 2.46). Time post stroke varied from one month to 40 months (M = 11.3; SD = 15.47). Descriptive information for these RBD subjects is provided in Table 2-2.

Table 2-1 LBD Subject Identification

Subject	Sex	Age	Education	MPO*
L1	M	63	9	28
L2	M	79	3	53
L3	M	64	4	25
L4	M	70	15	84
L5	M	62	12	2
L6	M	79	14	168
L7	M	69	12	67
L8	M	62	12	261
L9	M	77	16	19
L10	F	45	15	16
L11	F	35	12	37
L12	M	55	12	28
L13	M	65	12	1
L14	F	58	13	4
L15	F	52	14	17
L16	F	55	12	1
L17	F	78	12	1
L18	F	56	12	1
L19	F	32	12	8
L20	M	48	14	8

*MPO – months post-onset

Table 2-2 RBD Subject Identification

Subject	Sex	Age	Education	MPO*
R1	M	76	13	40
R2	M	58	10	2
R3	M	59	16	27
R4	M	77	13	5
R5	M	62	12	4
R6	M	73	16	1
R7	F	54	8	1
R8	F	61	14	1
R9	M	62	12	1
R10	M	60	12	31

*MPO – months post-onset

The control subject group consisted of 10 neurologically intact community volunteers from Gainesville and Bradenton, Florida, and Spokane, Washington. All control subjects were also right-handed and native English speakers. Their ages ranged from 46 to 76 years (M = 64.1; SD = 8.62). Educational levels ranged from 10 to 16 years (M = 12.6; SD = 1.84). Descriptive information regarding the control subjects is provided in Table 2-3.

Table 2-3 Control Subject Identification

Subject	Sex	Age	Education
C1	M	69	13
C2	M	71	13
C3	M	63	12
C4	M	59	16
C5	F	69	12
C6	F	63	10
C7	M	68	14
C8	M	57	14
C9	M	76	10
C10	F	46	12

Materials and Methods

The description of the experimental procedures that follows is divided into two sections, each containing a description of the materials, methods of presentation, and scoring procedures relevant to each measure. The first section, entitled evaluation of independent variables describes tests designed to measure the deficits associated with inpairment in action planning and organization (*i.e.*, "frontal apraxia," a high level schema deficit), deficits in the production of learned, skilled movements (*i.e.*, ideomotor apraxia, a low level schema deficit), deficits in conceptual knowledge of tool-object-function relationships (*i.e.*, conceptual apraxia a low and/or high level schema deficit), and deficits in supervisory attention/working memory (high level schema deficit). In

addition, tests of language abilities and presence of neglect are described. Results of the tests of language and neglect were not used to directly answer the stated research questions. Rather, due to the co-occurrence of aphasia and apraxia in left hemisphere damaged patients and the occurrence of neglect in right hemisphere damaged patients, these variables must be systematically measured in order to assist in the interpretation of the results. The second section, entitled evaluation of dependent variables describes a task designed to measure production of movement and action errors in an activity of daily living.

All subjects were administered the same battery of tests. Testing occurred within one day or across a two-day period. The order of presentation of all tests was randomized across subjects.

Evaluation of Independent Variables.

Disorders of action planning and organization

Materials. The Tower of London task (TOL, Shallice, 1982; Krikorian, Bartok, & Gay, 1994) was given to evaluate deficits in the ability to plan and organize actions associated with "frontal apraxia." The TOL consists of three pegs of different lengths mounted on a strip of board and three colored balls (red, green, and blue). The balls have holes drilled through them so they can be placed on the pegs. The left peg held all three balls, the middle peg held two balls, and the right peg held one ball.

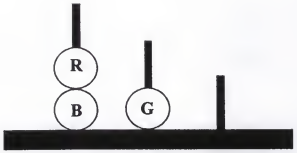
Methods. The standardized administration procedures described by Krikorian *et al.* (1994) were used in this study. The balls were placed in a standard initial position (red ball on top of green ball on left peg and blue ball on middle peg) and the subject was

asked to manipulate the balls on the pegs to reproduce a pictured end state (Figure 2-1). The subject performed twelve trials of increasing difficulty. A problem was correctly solved when the end state was achieved in the prescribed number of moves. The subject had three attempts to solve each trial.

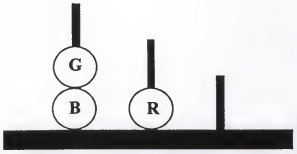
Scoring. The standardized scoring procedures described by Krikorian *et al.* (1994) were used in this study. The subject received three points if the trial was solved correctly on the first attempt; two points if solved on the second attempt; one point if solved on the third attempt; and zero points if not solved by the third attempt. The examiner scored each subjects' performance online according to the above mentioned criteria and percent correct was calculated by dividing the number of points accumulated by the total number of points possible.

Disorders of learned, skilled movements

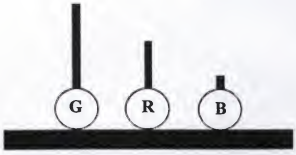
Materials. The Randomized Form A (RFA) and Randomized Form B (RFB) versions of the Gesture to Command subtest of the Florida Apraxia Battery: Experimental Edition (Appendices A & B, Rothi, Raymer, Ochipa, Maher, Greenwald, & Heilman, 1992) were given to evaluate presence and severity of disorders of learned, skilled movements associated with ideomotor apraxia. The Gesture To Command subtest consists of 30 commands which elicit transitive or intransitive gestures. Transitive gestures (*e.g.*, show me how you use a hammer) involve tool knowledge and demonstration of how one uses tools. Intransitive gestures (*e.g.*, show me how you would salute) do not involve tool knowledge and have been defined as emblems by Lemay, David, and Thomas (1989). (See Appendix A for copies of the RFA and RFB).



Initital State



End State - 3 moves



End State - 5 moves

Figure 2-1. The Tower of London (from Krikorian, Bartok, & Gay, 1994).

To control for the possible effects of hand used to gesture, Raymer, Maher, Macauley, Foundas, Rothi, and Heilman (1997) studied the performance of 16 neurologically normal, right handed control subjects on this Gesture to Command subtest looking at the influence of hand used. They divided the 16 subjects into four groups and administered the RFA or RFB counterbalancing hand used to gesture in the following manner: Group 1 was administered RFA and gestured all items with the right hand followed by all items with the left hand; Group 2 was administered RFA with the left hand used first; Group 3 was administered RFB with the right hand used first; and Group 4 was administered RFB with the left hand used first. The tapes were then scored pass/fail by two raters with at least two year's experience in scoring gesture production using the Rothi, Mack, Verfaellie, and Brown (1988) error pattern analysis. Results indicated that there was no significant difference in the performance of the right and left hands by control subjects with no history of neurological disease when producing gestures to command (Raymer *et al.*, 1997).

Methods. Each subject was administered either the RFA or RFB using the instructions written at the top of each score sheet (See Appendix A). The RFA and RFB were alternated across subjects with half receiving RFA and half receiving RFB. To control for possible effects of hemiparesis, the experimental subjects produced the gestures using their ipsilesional hand and five of the ten control subjects were asked to gesture using their non-dominant left hand. The subjects were videotaped while performing these gestures.

Scoring. The videotapes were scored by two examiners familiar with ideomotor apraxia who underwent a training session similar to that described by Maher (1995). During the training sessions, the examiners were required to obtain at least 85% agreement with practice tapes before beginning to score the experimental tapes. The scoring system followed the error pattern analysis described by Rothi *et al.* (1988). Each gesture was given a pass/fail rating and percent correct was calculated.

Inter-rater reliability was calculated by having the raters score four videotapes twice and calculating percent agreement across the two sessions. Intra-rater reliability was calculated by calculating percent agreement between the two scorers on 20% of the videotapes.

Disorders of tool-object-function knowledge

Materials. A revised version of the Tool-Object Matching Test (TOM) described by Ochipa *et al.* (1989) was given to evaluate deficits in tool-function-object knowledge associated with ideational/conceptual apraxia (Appendix B). The original version of the Tool-Object Matching Task described by Ochipa *et al.* (1989) used randomly generated tools as foils. The revised version used the same foil tools for each trial across subjects. The foil tools were drawn from the possible correct tool choices for the other trials and all tools were used three times - once as a correct answer and twice as foils (except for hammer which is a correct answer twice and used as a foil four times).

Methods. Each subject was presented with a partially completed task (*e.g.* a partially sawed board) and an array of three tools consisting of the target tool and two foil tools (*e.g.* a hammer, saw, and pencil). The subject was asked to select the appropriate

tool to complete the task according to the instructions written at the top of the score sheet (Appendix B).

Scoring. The examiner scored the subject's responses online using a binomial, pass/fail criteria and percent correct responses was calculated.

Disorders of supervisory attention/working memory

Materials. The Trailmaking Test - Parts A & B (Reitan, 1944) was used to evaluate deficits in supervisory attention/working memory. The Trailmaking Tests - Parts A & B ("Trails A & B") are standardized neuropsychological measures that are sensitive to brain damage. Good performance on Trails A & B depends upon attention to task and working memory with strong visual search and motor performance components. The standardized test sheets were used in this study. Trails A & B each consist of a single sheet of 8 1/2 x 11 white paper with the numbers 1 - 25 (Part A) and 25 numbers and letters (Part B) written in random order on the page. The numbers and letters are written in circles.

Methods. Trails A & B were administered according to the standardized instructions by the examiner.

Scoring. Trails A & B were scored according to the standardized instructions by the examiner. The time in seconds required for the subject to complete Part A and Part B were recorded separately and compared to normative data reported by Davies (1968) (Appendix C).

Disorders of language

Materials. The Western Aphasia Battery (WAB, Kertesz, 1981) was used to evaluate presence, type, and severity of aphasia. The WAB is a standardized test of acquired language disorders which enables the calculation of aphasia severity through an aphasia quotient (AQ) and determination of aphasia type through the WAB aphasia type taxonomy. The WAB is divided into four sections, spontaneous speech, comprehension, repetition, and naming, which test each aspect of verbal language skills in brain-injured patients.

Methods. The WAB was administered according to the standardized instructions by the examiner, a certified speech-language pathologist with seven years experience working with neurologically based communication disorders.

Scoring. The WAB was scored according to the standardized instructions by the examiner, a certified speech-language pathologist with seven years experience working with neurologically based communication disorders. An aphasia quotient reflecting aphasia severity score was calculated and type of aphasia was documented based upon the WAB aphasia taxonomy (Kertesz, 1981).

Neglect

Materials. A line bisection task was used to evaluate presence and severity of neglect. For the current study, three lines measuring eight, ten, and twelve inches in length were drawn horizontally across the middle of individual 11x14 pieces of paper using a thick black marker.

Methods. The examiner placed one of the pieces of "lined" paper described above horizontally on the table approximately eighteen inches in front of the subject with the middle of the line even with the subject's midsagittal plane. The subject was given a pen and asked to "mark the center of the line." This procedure was repeated for each of the three lines. The lines were given in random order to each subject.

Scoring. The examiner scored the accuracy of the subject's mark by measuring the difference between the true middle of the line and the subject's mark. An average difference was calculated in centimeters. Presence of neglect was determined by a difference score of 10mm between the true midline and the subject's mark (Heilman, Watson, & Valenstein, 1985). Severity of neglect was determined by the magnitude of the average difference in that the greater the difference, the more severe the neglect.

Evaluation of Dependent Variable--Eating a Meal.

Materials. A meal consisting of a main course, at least one side dish, a dessert, and a beverage, and utensils such as a knife, fork, and spoon, were organized on a hospital tray according to standard etiquette rules. The food was placed on standard hospital plates with covers. Additionally, three foil items - a toothbrush, comb, and pencil, were also placed on the tray interspersed in random order with the utensils. The location of the foil items and the utensils were ipsilateral to side of lesion for the experimental subjects and counterbalanced across control subjects. Subjects who were inpatients received their meals in their hospital rooms from food service personnel during regular mealtimes. Subjects who were not inpatients obtained their meals through the hospital cafeteria using similar plates and covers as the inpatients and ate privately in a

research laboratory. Straws, condiments, and napkins were made available to each subject by the examiner.

Methods. All subjects were videotaped while eating the meal. The videotaping was done using a Sharp videocamera set on a tripod approximately five feet in front of the subject. Taping was done on a TDK 120 minute videotape. The video camera was turned on just prior to the subject receiving their food and turned off after completion of the meal. The examiner was not in the room during the videotaping and nurses, spouses or significant others were instructed not to assist the subject in any way during the eating of the meal, unless specifically asked to do so by the subject. Conversation with family members during the meal was allowed to ensure a comfortable, natural environment. The examiner arranged the utensils and foil items on the tray after the meal had been delivered counterbalancing location (right or left) across control subjects. Subjects with specific dietary restrictions were accommodated through choice of meal. In order to control for possible effects of hemiparesis, an equal number of control subjects were asked to eat with their nondominant hand as experimental subjects who ate with their nondominant hand.

Scoring. The mealtime videotapes were scored by two raters and a trainer at the same time but independently. The scoring was completed in a quiet room using a 20 inch viewing monitor and a Sony video player with slow motion and freeze frame capabilities. The trainer controlled the tape player for the raters but the raters were free to stop and rewind to view an action or series of actions as many times as necessary to ensure that all actions produced by the subjects were included. The raters were encouraged to consult a

list of error types given to them during the training time as often as needed during the scoring periods. No discussion was allowed with respect to the subject's performance and the raters were not able to see each other's or the trainer's score sheet.

The scoring system described by Foundas *et al.* (1995) and the error classification system associated with the proposed relationship between apraxia and pragmatic action described in chapter one was used in this study. For the current study, an action was defined as a sequence of individual movements that result in the accomplishment of a definable goal and movements were defined as changes in place, position, or posture. For example, picking up the fork, piercing a piece of meat, and bringing the meat to the mouth would be three individual movements that make up one action. Each action was categorized as a tool or a nontool action. Examples of tool actions would be stirring tea with a spoon; eating a piece of meat with a fork ; and buttering a slice of bread with a knife. Examples of nontool actions would be placing the napkin in the lap; moving an empty plate to the side of the tray; and opening a packet of sugar. The raters were instructed to use a standard recording form to record the quadrant of the tray in which the action was initiated, which hand was used to perform the action, which tool and object were used, and which action was performed. The raters then determined if the action was correct or incorrect and if judged incorrect, the raters assigned an error type to the incorrect action. The error types are described below:

Errors proposed to result from Low Level System Impairment:

> internal configuration: hand posture used to manipulate tool was incorrect (*e.g.*, holding a spoon with a tightened fist).

external configuration: action produced was misplaced in space in absence of perceptual deficits (*e.g.*, scooping with a spoon on the table beside the plate).

body part as tool: action was produced using a body part as the tool (*e.g.*, spreading butter on bread with index finger).

timing: incorrect timing during a sequence of movements within one action (*e.g.* spreading butter on bread with pauses in between the knife movements) or between two actions (*e.g.*, holding a spoonful of food close to the mouth while one is still chewing a previous bite).

quantity: incorrect or inefficient amount of food is taken to the mouth (*e.g.*, putting too much or too little mashed potatoes on a spoon which is then brought to the mouth).

movement: movement produced was inaccurate or incorrect (*e.g.*, using wrist motion rather than shoulder motion)

Errors proposed to result from high level system impairment:

sequence: sequence of actions was incorrect (*e.g.*, stirring tea before adding the sugar)

omission: omitting one action from a sequence of actions (*e.g.*, putting sugar in tea and not stirring it at all).

addition: adding an additional action during a sequence of actions (*e.g.* putting sugar in tea and eating a bite of food before stirring the tea).

Errors proposed to result from high and/or low level system impairment:

misuse: action (movement) produced was incorrect for chosen tool (*e.g.*, stirring with a knife) (See Figure 1-7.)

mis-selection: action (movement) produced was correct for the chosen tool but not for the goal with the object (*e.g.*, using a fork to eat ice cream) (See Figure 1-7.)

It was possible for one action to be judged as represented by more than one error type during the scoring procedure.

Actions over the entire meal were recorded and scored and the following calculations were obtained:

1. percent correct tool actions:

$$\frac{\text{\# of correct tool actions}}{\text{total \# of tool actions}}$$

2. percent correct nontool actions:

$$\frac{\text{\# of correct nontool actions}}{\text{total \# of nontool actions}}$$

3. percent correct total actions:

$$\frac{\text{\# of total correct actions (tool + nontool)}}{\text{\# of total actions (tool + nontool)}}$$

4. action per time ratio:

$$\frac{\text{total time of meal (seconds)}}{\text{total \# of errors over the entire meal}}$$

Rater Training

The rater training protocol used in this study was based on the protocol described by Maher (1995). The raters for this study were two graduate students in speech-language pathology. The raters were novices in the study of apraxia and unfamiliar with the specific research questions in the study. The raters were told that every action the subjects produced was important and to make sure that every action was recorded and scored. Prior to a scoring session, the raters were given a score sheet and a list of error types with definitions and examples. They were asked to record and score a two minute portion of a mealtime tape from a previous study. These recordings and scores were reviewed with the raters by the examiner. Any discrepancies in scoring were reevaluated

by watching the pertinent section of the videotape and then discussing the scores. This procedure continued until 85% or greater reliability between the raters was achieved over 16 trials (one trial = one action). At that point, the error types were reviewed by the trainer and recording/scoring of test trials began.

Inter-rater reliability was calculated by selecting four videotapes at random and calculating point-to-point reliability for the raters. The raters were not aware of which subjects were used for reliability calculations. Two subjects selected at random were scored twice by the raters to calculate intra-rater reliability.

Statistical Analyses

The statistical analyses were tailored specifically for each of the research questions. For question number 1

> Does brain damage in either hemisphere result in production of action errors in the natural environment or are action errors specific to left hemisphere brain damaged patients?

the LBD, RBD, and control subjects were compared using an analyses of variance with the dependent variable being total number of action errors produced during the eating task. Because a negatively skewed distribution was found for the control subjects, a nonparametric test, the Kruskal-Wallace, was used. The Wilcoxon Rank Sums Test was then used to determine differences between groups.

For question 2a

Does presence of deficits in

1. production of learned skilled movements,
2. conceptual knowledge of tool-function relationships,
3. action planning and organization, and
4. supervisory attention/working memory

predict production of action errors in the natural environment?

Pearson Product Moment Correlations were calculated between the independent experimental measures (TOL, FAB, WAB, Trails A, Trails B, Neglect, Tool-Object Matching) and total number of action errors produced during the meal.

For question 2b

> And if so, to what extent does each type of deficit (low level system deficits--1 and 2 above and high level system deficits--3 and 4 above) predict type of error (including misuse, mis-selection, external configuration, internal configuration, timing, quantity, sequence [omission, addition, sequence], exchange, substitution, movement, and body part as tool)?

A multiple stepwise regression statistic was calculated between the independent measures (TOL, FAB, Trails A, Trails B, Tool-Object Matching) and the dependent variables of types of errors produced during the meal (misuse, mis-selection, external configuration, internal configuration, timing, sequence [omission, addition, sequence], movement, and body part as tool.

CHAPTER THREE
RESULTS

The purpose of this study was to examine the nature of movement and action errors produced by brain-damaged patients during an activity of daily living--eating a meal. Two experimental subject groups and one control subject group participated in this study. The first experimental group consisted of twenty left hemisphere brain-damaged patients; the second experimental group consisted of ten right hemisphere brain-damaged patients; and the control subject group consisted of ten neurologically normal control subjects. There were no significant differences between the three groups in age $F(2, 37) = 0.61$, $p > 0.54$ or educational level $F(2, 37) = 0.36$, $p > 0.69$. There was also no significant different in the time post stroke between the two experimental groups $F(1, 28) = 2.04$, $p > 0.16$.

Experimental Results

Errors of movement and action were theorized to occur at two levels based on the low (movement) and high (action) level schema systems proposed by the relationship described in Figure 1-4. That is, error types that reflect deficits in the praxis production system (Rothi *et al.*, 1991) would make up low level schematic system errors while error types that reflect deficits in the planning and organization of action in the executive function and control mechanisms (Schwartz & Buxbaum, 1997) would make up high level schematic errors. As described in Chapter Two, the evaluation of independent variables included tests that were proposed to measure the different deficits that can

occur within the two levels. The Tower of London (TOL; Shallice, 1982, Krikorian *et al.*, 1994) was given to evaluate deficits in the ability to plan and organize actions associated with "frontal apraxia", a high level deficit. The Gesture to Command subtest of The Florida Apraxia Battery: Experimental Edition (Rothi *et al.*, 1992) was given to evaluate the presence and severity of disorders of learned, skilled movement associated with ideomotor apraxia, a low level deficit. A revised version of the Tool-Object Matching Test (TOM) described by Ochipa *et al.*, (1989) was given to evaluate deficits in tool-function-object knowledge associated with ideational/conceptual apraxia, a low level deficit. Additionally, the Trailmaking Test – Parts A & B (Reitan, 1944) was given to evaluate deficits in supervisory attention/working memory; The Western Aphasia Battery (WAB; Kertesz, 1981) was given to evaluate presence of aphasia; and a line bisection task was used to evaluate presence of neglect. Descriptive statistics for the three groups on each of the above tasks are listed in Table 3.1. Overall, the three groups were prototypic of their constituents. That is, 70% of the RBD had neglect while only 40% of the LBD and none of the controls had neglect. 85% of the LBD had aphasia while none of the RBD or controls were aphasic. 65% of the LBD had ideomotor apraxia while 20% of the RBD and none of the controls were apraxic. 20% of the LBD and none of the RBD or controls had conceptual apraxia. In addition, 80% of LBD and 70% of RBD had "frontal apraxia" and were slower on the attention tasks than the controls.

Neglect and aphasia were ruled out as variables that affected the data by dividing all subjects into two groups according to presence/absence of neglect and presence/absence of aphasia and comparing the mean number and types of errors produced by the two groups. No significant differences between the groups were found.

Table 3.1 Descriptive Statistics for Each Group on Measures of Independent Variables

Task	Mean	SD	Max	Min
Tower of London				
LBD	24.4	11.21	34	3
RBD	24.1	10.21	33	5
Control	30.8	3.08	35	26
Total Possible	36			
Gesture to Command				
LBD	12.8	6.03	25	3
RBD	20.8	6.01	27	10
Control	23.0	3.13	28	17
Total Possible	30			
Tool-Object Matching				
LBD	9.3	1.94	10	3
RBD	10	0	10	10
Control	10	0	10	10
Total Possible	10			
Trails A				
LBD	86.71	56.98	232	26
RBD	112.2	74.68	231	39
Control	49.2	23.55	95	21
Range for NBD* varies according to age, (Appendix C)				
Trails B				
LBD	208.1	197.45	925	67
RBD	213.5	154.15	561	100
Control	111.3	47.78	199	66
Range for NBD* varies according to age, (Appendix C)				
Western Aphasia Battery				
LBD	69.54	27.20	98.2	10.8
RBD	97.92	1.14	99.6	96.1
Control	99.02	0.64	99.8	98.2
Total Possible	100			
Line Bisection				
LBD	-1.6	1.56	13.3	-31.04
RBD	8.9	2.87	25.0	- 2.33
Control	2.9	0.39	0.67	- 7.00
Range for NBD*				

*NBD= non brain-damaged individuals

Research Questions

Research Question #1

Does brain damage in either hemisphere result in production of action errors in the natural environment or are action errors specific to left hemisphere brain damaged patients?

To determine if patients with LBD (left brain damage) and RBD (right brain damage) produce action errors in the natural environment, the following null hypothesis was tested:

H_o: There is no significant difference between the mean number of errors produced while eating a meal for the LBD, RBD, and control groups (NBD, non-brain damaged).

Using a Kruskal-Wallis One-Way Analysis of Variance on Ranks (due to the skewdness of the control group having produced no errors during the meal), the mean number of total errors was compared between the three groups. A significant between group difference was found (Table 3.2).

Table 3.2 Overall Kruskal-Wallis ANOVA for Errors Produced During the Meal

Task	ANOVA dF (2,2) Chi-Square H Statistic	P-Value
Total Errors	16.091	0.0003*
Tool Errors	10.496	0.0053*
Non-Tool Errors	15.479	0.0004*

* significant at p>0.01

Because a significant difference was found for total number of errors produced during the meal, a follow-up analysis was conducted using the Kruskal-Wallis Multiple Comparison Z-Value Test. This test is used to examine group differences with non-

parametric data. Results of the follow-up analyses, comparing each brain-damaged group with the normal controls are listed in Table 3.3. For total number of errors produced during the meal, the LBD and RBD groups did not differ from each other. However, both groups did differ significantly from the control group.

Table 3.3 Comparison of LBD and RBD Groups with Normal Controls

Group1 vs. Group 2	Critical Difference	Actual Difference
Total Errors		
LBD vs. RBD	z-value >1.96	1.012
LBD vs. Controls	z-value >1.96	3.997*
RBD vs. Controls	z-value >1.96	2.585*
Tool Errors		
LBD vs. RBD	z-value >1.96	2.269*
LBD vs. Controls	z-value >1.96	2.937*
RBD vs. Controls	z-value >1.96	0.5783
Non-Tool Errors		
LBD vs. RBD	z-value >1.96	0.568
LBD vs. Controls	z-value >1.96	3.861*
RBD vs. Controls	z-value >1.96	2.851*

*significant at p>0.01

In order to determine if the significant difference found for number of total errors could be accounted for by differences in number of tool errors and/or nontool errors produced by the three groups, additional ANOVAs were calculated for total number of tool errors and nontool errors. Significant group differences were found for both tool and nontool errors. See Table 3.2 for ANOVA results. To examine between group comparisons, follow-up analyses were conducted using the Kruskal-Wallis Multiple

Comparison Z-Value Test. Results indicated that the LBD group differed significantly from both the RBD and control groups in number of tool errors produced but the RBD group did not differ from the control group. In addition, both of the LBD and RBD groups differed significantly from the control group in number of nontool errors produced but the LBD and RBD groups did not differ from each other. (See Table 3.3.)

Research Question #2a

2a. Does presence of deficits in
1. production of learned skilled movements,
2. conceptual knowledge of tool-function relationships,
3. action planning and organization, and
4. supervisory attention/working memory
predict production of action errors in the natural environment?

To determine if there is a relationship between the presence of deficits in 1, 2, 3, or 4 above, with production of action errors, the following null hypothesis was tested:

H_o: There is no correlation between deficits in 1, 2, 3, or 4 with number of errors produced during the eating task across the three subject groups.

Using a Pearson-Product Moment Correlation Statistic, relationships between scores on the Gesture to Command subtest of the Florida Apraxia Battery: Experimental Edition (Rothi *et al.*, 1992) which measures deficit #1 above, the tool-object matching test (Ochipa *et al.*, 1989) which measures deficit #2 above, the Tower of London (Shallice, 1982, Krikorian *et al.*, 1994) which measures deficit #3 above, and Trails A and Trails B (Reitan, 1944) which measure deficit #4 above, were correlated with total number of errors produced during the meal. Results of this analysis revealed that the highest correlation was with the TOL and the lowest correlation was with the tool-object matching task. All correlations are listed in Table 3.4.

Table 3.4 Pearson-Product Moment Correlation Report

	Total Errors
Gesture to Command	-0.389
Tool-Object Match	-0.083
Tower of London	-0.550
Trails A	0.247
Trails B	0.244

In addition to the correlation statistic, all subjects were divided into two groups according to the normal versus abnormal cut-off score for each of the independent variables. Two sample t-tests were then calculated for the mean number of overall errors (total, tool, and non-tool) as well as for the mean number of specific error types (misuse, misselection, movement, INT, sequence, timing, and quantity) produced by the normal/abnormal groups. Parametric or non-parametric t-tests were chosen based on the normalcy and the variance of the data within each error type on these various tests. These divisions and analyses were completed in order to obtain a better understanding of the influence of the grouping variables (deficits in #1, 2, 3, and 4 from question 2a) on error types in these various tests.

On the gesture to command task, all subjects were divided into two groups--those subjects scoring 14 or below, indicating presence of ideomotor apraxia (IMA), were in group 1 while those subjects scoring 15 or above indicating normal praxis skills (*i.e.* non-IMA) were in group 2 (Rothi *et al.*, 1992). Group 1 consisted of 15 subjects while group 2 consisted of 25 subjects. The two groups were then compared in each of the overall and specific error types listed previously. Results indicated that there were significant

differences between the two groups at the $p<0.01$ level for total number of errors as well as for number of tool, misuse, movement, timing, and quantity errors produced during the meal. In contrast, no significant differences were found for number of non-tool errors as well as for number of misselection, INT, and sequence errors produced during the meal. See Tables 3.5 and 3.6.

Table 3.5 Average Number of Errors Produced by All Subjects When Divided into Two Groups According to Cut-Off Score for Each Test.

Test	Cut-Off Score	n	Average Number of Errors		
			Total	Tool	NonTool
Ideomotor Apraxia[1]	15-30	25	4.32*	1.08*	3.24
	< 15	15	17.87	9.87	7.93
Conceptual Apraxia[2]	10	36	8.97*	4.00*	4.94*
	< 10	4	14.33	9.33	5.00
"Frontal Apraxia"[3]	33-36	12	1.25*	0.17*	1.10*
	< 33	28	12.63	5.88	6.71
Attention[4]	> 25th per.	18	1.94*	1.50	0.45*
	< 25th per.	18	10.44	4.22	6.16
Divided Attention[5]	> 25th per.	19	3.26*	0.11*	3.16*
	< 25th per.	16	9.94	6.31	3.56

[1] Rothi *et al.*, 1992
[2] Ochipa *et al.*, 1992
[3] Krikorian *et al.*, 1994
[4,5] Spreem and Strauss, 1991
n = number of subjects in group
per. = percentile
* = significant at the $p<0.01$ level

Table 3.6 Average Number of Errors by Specific Error Type Produced by LBD, RBD, and Control Groups

Test	Cut-Off Score	Average Number of Errors						
		Misuse	Misselection	Movement	INT	Sequence	Timing	Quantity
Ideomotor Apraxia[1]	15-30	0.20*	0.28	0.20*	0.40	1.00	0.92*	1.24*
	< 15	5.67	0.67	1.93	1.60	0.60	2.00	4.27
Conceptual Apraxia[2]	10	2.39	0.47	0.67	0.47	0.94	1.19	2.31
	< 10	1.33	0.00	2.33	5.67	0.00	2.00	3.00
Frontal Apraxia[3]	33-36	0.00	0.00	0.17	0.00	0.00*	0.58	0.50*
	< 33	3.25	0.29	0.92	1.42	1.42	1.21	3.34
Attention[4]	> 25th percentile	0.28	0.39	0.28	0.56	0.17	0.11*	0.11*
	< 25th percentile	2.11	0.56	1.33	0.22	1.17	2.39	2.56
Divided Attention[5]	> 25th percentile	0.00*	0.00	0.11*	0.00	0.74	1.31	1.11*
	< 25th percentile	2.6	1.6	1.6	0.8	0.3	1.5	1.63

[1] Rothi *et al.*, 1992.
[2] Ochipa *et al.*, 1992.
[3] Krikorian *et al.*, 1994.
[4,5] Spreem and Strauss, 1991
* = significant at the $p<0.01$ level

On the tool-object matching task, all subjects were divided into two groups according to the following criteria. Those subjects scoring 9 or below, indicating presence of conceptual apraxia were in group 1 while those subjects scoring 10, indicating normal praxis skills, were in group 2 (Ochipa *et al.*, 1992). Group 1 consisted of 4 subjects while group 2 consisted of 36 subjects. The two groups were then compared in each of the overall and specific error types listed previously. Results indicated that there were significant differences between the two groups at the $p<0.01$ level for total number of errors as well as for number of tool and non-tool errors produced during the meal. In contrast, no significant differences were found for number of misuse, misselection, movement, INT, sequence, timing, or quantity errors produced during the meal. See Tables 3.5 and 3.6.

On the TOL task, all subjects were divided into two groups--those subjects scoring 32 or below, indicating presence of frontal apraxia were in group 1 while those subjects scoring 33 or above, indicating normal praxis skills, were in group 2 (Krikorian *et al.*, 1994). Group 1 consisted of 28 subjects while group 2 consisted of 12 subjects. The two groups were then compared in each of the overall and specific error types listed previously. Results indicated that there were significant differences between the two groups at the $p<0.01$ level for total number of errors as well as for number of tool, non-tool, sequence, and quantity errors produced during the meal. In contrast, no significant differences were found for number of misuse, misselection, movement, INT, and timing, errors produced during the meal. See Tables 3.5 and 3.6.

Fourth, all subjects were divided into two groups according to Trails A score. The criterion for this division was based on Table 8.12 (page 326) in A Compendium of

Neuropsychological Tests (Spreem & Strauss, 1991) which is a summary of normative data for completion of the Trails A task. Subjects were placed in group 1, indicating presence of poor attentional skills, if their time to complete Trails A was below the 25th percentile for their age. Subjects were placed in group 2, indicating normal attentional skills, if their time to complete Trails A was above the 25th percentile for their age group. Group 1 consisted of 18 subjects and group 2 also consisted of 18 subjects (four subject were unable to complete the task). The two groups were then compared in each of the overall and specific error types listed previously. Results indicated that there were significant differences between the two groups at the $p<0.01$ level for total number of errors as well as for number of non-tool, movement, timing and quantity errors produced during the meal. In contrast, no significant differences were found for number of tool, misuse, movement, INT, and sequence errors produced during the meal. See Tables 3.5 and 3.6.

Finally, all subjects were divided into two groups according to Trails B score. The criterion for this division was also based on Table 8.12 (page 326) in A Compendium of Neuropsychological Tests (Spreem & Strauss, 1991) which is a summary of normative data for completion of the Trails B task. Subjects were placed in group 1, indicating presence of poor divided attentional skills, if their time to complete Trails B was below the 25th percentile for their age. Subjects were placed in group 2, indicating normal divided attentional skills, if their time to complete Trails B was above the 25th percentile for their age group. Group 1 consisted of 16 subjects and group 2 consisted of 19 subjects (five subjects were unable to complete the task). The two groups were then compared in each of the overall and specific error types listed previously. Results

indicated that there were significant differences between the two groups at the $p<0.01$ level for total number of errors as well as for number of tool, non-tool, misuse, movement, and quantity errors produced during the meal. In contrast, no significant differences were found for number of misselection, INT, sequence, and timing errors produced during the meal. See Tables 3.5 and 3.6.

Research Question 2b

> 2b. And if so, to what extent does each type of deficit (low level schema deficits--1 and 2 from question 2a above and high level schema deficits--3 and 4 from question 2a above) predict type of error (including misuse, mis-selection, external configuration, internal configuration, timing, quantity, sequence, exchange, substitution, movement, and body part as tool)?

To determine if there is a relationship between the types of deficits (lower or higher level schema) and types of errors produced during the meal, a multiple stepwise regression statistic was calculated between the independent variables, FAB, tool-object match (TOM), TOL, Trails A, and Trails B, and the types of errors observed during the meal (tool, non-tool, and total errors as well as the individual types: misuse, misselection, internal configuration, movement, sequence, timing, and quantity). The results indicated that 0.22% of the variance for total errors can be explained through iteration 4 which included the FAB, TOL, Trails A, and TOM, respectively. The results of the multiple stepwise regression for total errors are displayed in Table 3.7.

Table 3.7 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Total Errors Produced During the Meal

Model Size	R^2	Model
1	0.11	Trails A
2	0.16	FAB + TOL
3	0.19	FAB + TOL + Trails A
4	***0.23***	***FAB + TOL + Trails A + TOM***

The results indicated that 0.37% of the variance for tool errors can be explained through iteration 4 which included the FAB, TOL, Trails A, and Trails B, respectively. The results of the multiple stepwise regression for tool errors are displayed in Table 3.8.

Table 3.8 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Tool Errors Produced During the Meal

Model Size	R^2	Model
1	0.24	Trails A
2	0.26	FAB + Trails A
3	0.32	FAB + TOL + Trails A
4	***0.37***	***FAB + TOL + Trails A + Trails B***
5	0.37	FAB + TOL + Trails A + Trails B + TOM

The results indicated that 0.06% of the variance for non-tool errors can be explained through iteration 2 which included the TOL, and TOM, respectively. The results of the multiple stepwise regression for non-tool errors are displayed in Table 3.9.

Table 3.9 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Non-Tool Errors Produced During the Meal

Model Size	R^2	Model
1	0.02	TOL
2	***0.06***	***TOL + TOM***
3	0.06	TOL + Trails B + TOM
4	0.06	TOL + Trails A + Trails B + TOM
5	0.06	FAB + TOL + Trails A + Trails B + TOM

The results indicated that 0.25% of the variance for misuse errors can be explained through iteration 3 which included the FAB, TOL, and Trails A, respectively. The results of the multiple stepwise regression for misuse errors are displayed in Table 3.10.

Table 3.10 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Misuse Errors Produced During the Meal

Model Size	R^2	Model
1	0.19	Trails A
2	0.22	FAB + Trails A
3	***0.25***	***FAB + TOL + Trails A***
4	0.26	FAB + TOL + TRAILS A + TRAILS B
5	0.26	FAB + TOL + TRAILS A + TRAILS B + TOM

The results indicated that 0.09% of the variance for misselection errors can be explained through iteration 4 which included the FAB, TOL, Trails A, and TOM, respectively. The results of the multiple stepwise regression for misselection errors are displayed in Table 3.11.

Table 3.11 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Misselection Errors Produced During the Meal

Model Size	R^2	Model
1	0.02	TOM
2	0.06	TOL + TOM
3	0.08	FAB + TOL + TOM
4	***0.09***	***FAB + TOL + Trails B + TOM***
5	0.09	FAB + TOL + Trails A + Trails B + TOM

The results indicated that 0.535% of the variance for movement errors can be explained through iteration 4 which included the FAB, TOL, Trails A, and Trails B, respectively. The results of the multiple stepwise regression for movement errors are displayed in Table 3.12.

Table 3.12 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Movement Errors Produced During the Meal

Model Size	R^2	Model
1	0.36	Trails A
2	0.39	TOL + Trails A
3	0.45	FAB + TOL + Trails A
4	***0.53***	***FAB + TOL + Trails A + Trails B***
5	0.53	FAB + TOL + Trails A + Trails B + TOM

The results indicated that 0.19% of the variance for INT errors can be explained through iteration 5 which included the FAB, TOL, Trails A, Trails B, and TOM, respectively. The results of the multiple stepwise regression for INT errors are displayed in Table 3.13.

Table 3.13 Results of Multiple Stepwise Regression Analysis Between Independent Variables and INT Errors Produced During the Meal

Model Size	R^2	Model
1	0.07	Trails A
2	0.10	Trails A + TOM
3	0.13	TOL + Trails A + TOM
4	0.17	FAB + TOL + Trails A + Trails B
5	***0.19***	***FAB + TOL + Trails A + Trails B + TOM***

The results indicated that 0.05% of the variance for sequence errors can be explained through iteration 4 which included the FAB, TOL, Trails A, and TOM, respectively. The results of the multiple stepwise regression for sequence errors are displayed in Table 3.14.

Table 3.14 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Sequence Errors Produced During the Meal

Model Size	R^2	Model
1	0.02	Trails A
2	0.03	Trails A + TOM
3	0.04	TOL + Trails A + TOM
4	***0.05***	***FAB + TOL + Trails A + TOM***
5	0.05	FAB + TOL + Trails A + Trials B + TOM

The results indicated that 0.08% of the variance for timing errors can be explained through iteration 4 which included the TOL, Trails A, Trails B, and TOM, respectively. The results of the multiple stepwise regression for timing errors are displayed in Table 3.15.

Table 3.15 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Timing Errors Produced During the Meal

Model Size	R^2	Model
1	0.02	TOL
2	0.05	TOL + TOM
3	0.06	TOL + Trails A + TOM
4	***0.08***	***TOL + Trails A + Trails B + TOM***
5	0.08	FAB + TOL + Trails A + Trials B + TOM

The results indicated that 0.10% of the variance for quantity errors can be explained through iteration 2 which included the TOL and TOM, respectively. The results of the multiple stepwise regression for quantity errors are displayed in Table 3.16.

Table 3.16 Results of Multiple Stepwise Regression Analysis Between Independent Variables and Quantity Errors Produced During the Meal

Model Size	R^2	Model
1	0.03	TOL
2	***0.10***	***TOL + TOM***
3	0.10	TOL + Trails A + TOM
4	0.10	TOL + Trails A + Trails B + TOM
5	0.10	FAB + TOL + Trails A + Trails B + TOM

Summary of findings

Regarding research question #1, it was found that:

- Patients with either LBD or RBD produce action errors during an eating task.

- People without brain damage do not tend to produce action errors during an eating task.
- LBD patients produce more tool action errors during an eating task than RBD patients who do not produce more of these errors than normal subjects.
- LBD and RBD patients produce equal amounts of non-tool errors during an eating task, both of whom produce more of these errors than normal subjects.

Regarding research question #2a, it was found that

- Presence of deficits in the production of learned, skilled movements to command, does predict presence of action errors in the natural environment.
- Presence of deficits in the conceptual knowledge of tool-function relationships, does predict presence of action errors in the natural environment.
- Presence of deficits in the action planning and organization, does predict presence of action errors in the natural environment.
- Presence of deficits in the supervisory attention/working memory, do predict presence of action errors in the natural environment.

Additionally,

- The measure of deficits in action planning and organization was the strongest predictor while the measure of deficits in conceptual knowledge

of tool-function relationships was the weakest predictor of total number of errors produced by the brain damaged patients during the eating task.

- Presence of deficits in production of learned, skilled movements appeared to influence production of tool but not non-tool errors during the eating task.
- Presence of deficits in supervisory attention/working memory appeared to influence production of non-tool but not tool errors.
- Presence of deficits in conceptual knowledge of tool-function relationships, and action planning and organization appeared to influence production of both tool and non-tool errors.

Regarding research question #2b, it was found that

- Neither low nor high level schema deficits independently predicted type of errors produced during the eating task, however, low and high level schema deficits when combined, predicted each error type produced during the eating task.
- However, the degree of their respective contributions varied according to error type produced during the eating task with movement errors receiving the strongest influence from both low and high level schema deficits followed by misuse, INT, quantity, timing, and sequence, respectively.

CHAPTER FOUR
DISCUSSION

Previous researchers have described errors of action produced during activities of daily living by patients with brain damage (Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Schwartz & Buxbaum, 1997; Ochipa *et al.*, 1989; Foundas *et al.*, 1995). However, each research team has examined the planning, organization, and production of these action errors through different theoretical models with different inherent assumptions and predictions. They have used different research hypotheses and evaluation criteria. Moreover, they have included subjects with heterogeneous etiologies of brain damage (Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; Schwartz & Buxbaum, 1997; Sirigu *et al.*, 1995a, 1995b, 1997; Ochipa *et al.*, 1989; Foundas *et al.*, 1995). The purpose of the current study was to examine the nature of action errors produced by brain-damaged patients during an activity of daily living--eating a meal--using a theoretical model which describes a proposed relationship between apraxia and pragmatic action. This model serves as a framework for the examination of the nature of action as well as movement errors and allows for comparison with models proposed by the previous researchers. Two experimental subject groups and one control subject group participated in this study. The first experimental group consisted of twenty left hemisphere brain-damaged patients (LBD); the second experimental group consisted of ten right hemisphere brain-damaged patients (RBD); and the control subject group consisted of ten

neurologically-normal control subjects. The groups were compared on experimental tasks designed to measure the deficits associated with impairment in action planning and organization (*i.e.*, frontal apraxia, a high level schema deficit), deficits in the production of learned, skilled movements (*i.e.*, ideomotor apraxia, a low level schema deficit), deficits in conceptual knowledge of tool-object-function relationships (*i.e.*, conceptual apraxia, a low and/or high level schema deficit), and deficits in supervisory attention/ working memory (high level schema deficit). Each subject was also videotaped while engaged in an activity of daily living--eating a meal--and the videotapes were subsequently scored for the presence of and type of movement and action errors. Statistical analyses then compared the groups for differences in the number and type of errors produced. Results indicated that the LBD, RBD, and control groups did differ in both the number and type of errors produced during the eating task which suggests that action errors can occur following unilateral damage to either hemisphere. Additionally, further analyses revealed that the number and type of errors produced differed according to the presence or the absence of higher and/or lower level schema deficits. Furthermore, this finding suggests that a stronger relationship appears between disorders of planning and organization (higher level schemas) and action errors during activities of daily living than disorders of learned, skilled movement (lower level schemas) and action errors during activities of daily living. However, both levels of deficits do contribute to production of errors in the natural environment. This chapter will discuss the results of the current study in respect to: 1) the research questions posed in Chapter One and results of previous

research, 2) clinical implications, 3) methodological issues and limitations of the study, and 4) implications for future research.

Research Questions

The primary question of interest for this study was: Does brain damage in either hemisphere result in production of action errors in the natural environment or are action errors specific to left hemisphere brain damaged patients? The major finding of this study was that brain damage in either hemisphere does result in production of action errors in the natural environment. Results indicated that both the LBD and the RBD groups produced significantly more errors overall than the control group. When the types of errors were broken down into tool errors and non-tool errors, the LBD and RBD groups differed from each other as well as with the controls. The LBD group produced significantly more tool errors than the RBD and the control group while the RBD group did not differ significantly from the control group. This difference was predicted in Chapter One where it was hypothesized that tool errors may be related to the presence of ideomotor apraxia, a low level schema deficit, in patients with damage to the dominant hemisphere. That is, previous research has shown that the visuokinesthetic engrams for learned skilled movement, which are damaged in ideomotor apraxia, are lateralized to the dominant (left) hemisphere. It would therefore be expected that the presence of ideomotor apraxia may affect production of tool errors and would be observed in the LBD group. Overall, thirteen of the twenty LBD subjects presented with ideomotor apraxia, while only two of the ten RBD subjects and no control subjects had ideomotor apraxia as defined by the Rothi *et al.* (1992) criteria.

Additionally, the LBD and RBD groups did not differ from each other, but both groups did differ significantly from the control group, in the number of non-tool errors produced during the meal. This finding was also predicted in Chapter One where it was hypothesized that non-tool errors may be more closely related to deficits in executive function and/or supervisory attention/working memory (high level schema deficits) which follow damage to either the dominant or non-dominant hemisphere. That is, both executive functions and supervisory attention/working memory have bilateral representation in the brain and can be impaired following damage to either hemisphere. In fact, all twenty LBD subjects and all ten RBD subjects demonstrated deficits in executive function (according to Krikorian *et al.* criteria 1994) and/or supervisory attention/working memory (according to Spreem & Strauss, 1991, criteria).

Furthermore, when the total number of errors produced was compared, the LBD subjects produced significantly more errors than the RBD subjects. This was also predicted in Chapter One where it was hypothesized that the LBD subjects were more likely to demonstrate both low level and high level schema deficits while the RBD subjects were more likely to demonstrate high level deficits only. As a result of this difference, the LBD subjects would have had more opportunities to produce errors secondary to deficits in both high and low level schemas.

The second research question was presented in two parts: Does presence of (a) deficits in production of learned skilled movements, (b) deficits in conceptual knowledge of tool-function relationships, (c) deficits in action planning and organization, and/or (d) deficits in supervisory attention/working memory predict

production of action errors in the natural environment? And if so, to what extent does each type of deficit (low level system deficits [a and b above] and high level system deficits [c and d above]) predict type of error (including misuse, mis-selection, external configuration, internal configuration, timing, quantity, sequence [omission, addition, sequence], exchange, substitution, movement, and body part as tool)? To answer the first question, a correlation statistic was calculated between the independent variables and the types of errors produced during the meal. Results indicated that overall, the measure of executive function had the highest correlation with all error types, tool, non-tool, and total errors. Also, the measure of ideomotor apraxia had the second highest correlation across all error types. These results also appear to support the hypothesis that high level schema deficits may "oversee" or dominate the entire action sequence and therefore may influence errors of each type within that action sequence when damaged. The fact that a measure of a low level schema deficit (ideomotor apraxia) had the next highest correlation across error types may indicate that low level schemas are equally important in the success of completing pragmatic actions as high level schemas. It was proposed in the described relationship between pragmatic action and apraxia in Chapter One that the final common pathway for pragmatic action was through the praxicon and movement formulae associated with low level schemas. Due to the close relationship between executive functions which govern pragmatic action overall, and the praxis system which governs the individual movement patterns which make up the pragmatic action components, it is logical that both would positively correlate with production of errors within natural contexts. It therefore also appears, that conceptual knowledge

about the relationship between tools and objects as well as supervisory attention/working memory may not play as important of a role in contributing to production of action errors because their correlations with the error types was not as high as either executive functions or ideomotor apraxia. This finding appears to contradict Ochipa *et al.* (1989), Schwartz *et al.* (1995), and Reason (1990). Ochipa *et al.* (1989) reported that their subject produced errors secondary to a deficit in conceptual knowledge about tool-object relationships while both Schwartz *et al.* (1995), and Reason (1990) discussed the importance of supervisory attention/working memory in "preventing" and "catching" action errors before they occur. However, the current study does not negate the importance of either conceptual knowledge of tool-object relationships or supervisory attention/working memory in producing pragmatic action. The significance of both was discussed in the proposed relationship between pragmatic action and apraxia in Chapter One. However, the current study does examine the roles of these components in regard to the production of action errors in brain-damaged patients. Within this context, it appears that executive function and ideomotor apraxia appear to correlate more highly than either conceptual knowledge of tool-object relationships or supervisory attention/working memory in the production of action errors during an activity of daily living.

To answer the latter part of the second question, the subjects were divided into two groups according to the presence or absence of each independent variable and t-tests were calculated between the two groups for each error type observed. When subjects were divided according to presence or absence of ideomotor apraxia, a low level schema deficit, it was predicted that error types associated with low level

schema deficits would predominate. However, the subjects with ideomotor apraxia produced errors in each category, not just those associated with low level schemas. Additionally, when the subjects were divided according to presence or absence of executive function disorders, conceptual knowledge of tool-object relationships, and supervisory attention/working memory, all high level schema deficits, the error types produced also were categorized into each category, not just those associated with high level schemas. Therefore, in order to better understand the relationship between each component and the error types, the relative pattern of errors must be compared and not just whether or not the error was produced. When the pattern of errors is compared, it appears that both presence of executive function disorders and ideomotor apraxia result in a high number of misuse and quantity errors. Both misuse and quantity errors are the only error types which can be explained by both low level and high level schema deficits. For misuse errors resulting from a low level schema deficit, the error would result from choosing the wrong action for the tool (or vice versa) while a high level schema deficit would result from using the tool from a previous action for the next action without considering that it is the wrong action. For quantity errors resulting from low-level schema deficits, the error would result from a deficit in the acknowledgement of the mechanical advantage that tools provide (*e.g.*, a spoon can only hold so much mashed potatoes without compromising the efficiency of the action) while quantity errors resulting from high level schemas result from the failure of the attentional system to mediate an inappropriate action.

When the pattern of errors is compared following the division of the subjects according to presence or absence of deficits in supervisory attention/working

memory, not only do misuse and quantity errors predominate, but also timing errors. This appears to indicate that misuse and quantity errors are the most prevalent errors following brain damage. It also suggests that attentional deficits contribute to timing errors. This relationship is also logical in that if one is not paying attention to the task, one may lose track of what action is supposed to be produced next and may therefore take extra time in deciding what action plan to initiate next in order to complete the task.

When the pattern of errors is compared following the division of the subjects according to presence or absence of deficits in the conceptual knowledge of tool-object relationships, the predominate error types were not misuse and quantity but movement and INT. This finding appears to contradict the proposal that deficits in the conceptual knowledge of tool-object relationships is a high level schema deficit because both movement and INT errors are specifically observed and produced by patients with ideomotor apraxia, a low level schema deficit. However, only four of the thirty brain damaged patients presented with deficits in the conceptual knowledge of tool-object relationships and these same four subjects also had severe ideomotor apraxia. It may be possible that the error patterns are a reflection of the severe ideomotor apraxia rather than a specific deficit in the conceptual knowledge of tool-object relationships.

Results of the above error pattern analyses support the proposals described by Schwartz *et al.* (1992, 1995) that errors produced by brain-damaged patients can result from an impairment in either the top-down or bottom-up level of processing. In this study, top-down processing would reflect deficits in high level schemas

influencing deficits in low-level schemas while bottom-up processing would reflect deficits in low level schemas that appear to be produced independently of high level "supervision" during the task. Subjects in the current study produced error types following both of these scenarios. Schwartz *et al.* (1992, 1995) also proposed that actions are not whole programs, but are organized into hierarchies that are activated in succession by the executive function system in order to complete the task. If this is true, then different parts of an action plan may be differentially affected by errors depending on the high versus low level of deficits. This was also observed in the errors produced by subjects in the current study. The overall task of eating a meal was completed but the subjects produced errors throughout and the errors were not produced consistently on the same action.

These results also appear to add additional information to the results of the Foundas *et al.* (1995) study. Foundas and colleagues reported that the errors of action observed in their subjects resulted from presence of ideomotor apraxia. However, Foundas *et al.* (1995) did not test for deficits in high level schemas and the subjects from both the Foundas *et al.* (1995) and the current study were patients with unilateral damage to either hemisphere following a stroke. It would appear that the deficits in high level schemas demonstrated by the stroke patients in the current study may also have been present in the subjects from the Foundas *et al.* (1995) study. Therefore, the errors produced by the subjects in the Foundas *et al.* (1995) study may also have been influenced by deficits in high level schemas.

In order to determine the degree of influence from each type of deficit, high level schema and low level schema, an all-possible regression statistic was calculated

between the independent variables and the specific error types. Results of these analyses revealed that no one independent variable can be distinguished from any other independent variable in their relative influence to production of action errors. That is, each error type appears to be influenced by both high and low level schema deficits. This finding also supports proposals made by Schwartz and Buxbaum (1997) in their discussion of the Unified Hypothesis. Schwartz and Buxbaum (1997) argued that it is the combination of deficits that results in action errors in natural contexts. That is, deficits in executive function may not result in action errors unless a deficit in the automaticity of the action schemas is also present. This may be observed in the present study by defining automaticity of action schemas as a low level schema deficit in the praxicon, which holds the programs for learned, skilled movements. By using this definition, only a combination of high level schema deficits and low level schema deficits should result in production of action errors. When this criteria is applied to the subjects in the current study, only one subject did not evince deficits in both high and low level schemas and this subject did not produce any action errors during the meal. Although this appears to support Schwartz and Buxbaum's (1997) proposal, there were an additional eleven subjects who presented with high level schema deficits only who did produced action errors during the meal. These eleven subjects should not have produced errors if Schwartz and Buxbaum's (1997) proposals were valid. It is also interesting to note that none of the subjects in the current study who demonstrated low level schema deficits had spared high level schemas. This would appear to support the bilateral nature of the high

level schemas as well as the lateralization of low level schemas discussed in the previous section.

Methodological Issues and Limitations of the Study

The results of this research must be interpreted within the context of the limitations of the study. One possible area of concern involves subject selection. All experimental subjects did have CT/MRI documentation of single, unilateral strokes but the time post onset varied from one month to 261 months (21.9 years) post stroke. It is possible that the subjects who had survived their stroke for a longer period of time had developed coping skills and strategies for actions. However, when evaluating the data, even the subjects with the longest post-onset time produced errors of action. The presence of dysphagia was an exclusionary criteria because the subjects needed to eat a meal of regular consistency in order to give them opportunity to use all three utensils. It is possible that stroke patients with swallowing disorders may have greater deficits in action errors than stroke patients without swallowing disorders.

It may also be a concern that the procedures or evaluations chosen to measure the independent variables (TOL for executive function disorders, FAB for ideomotor apraxia, tool-object matching task for conceptual disorders of tool-object function knowledge, and Trails A and Trails B for supervisory attention/working memory disorders) may not be the most sensitive or valid. These measures were chosen due to their ease in administration. The subjects were able to comprehend the directions and perform the tasks accordingly. If more complex or longer measures had been chosen,

it would have been very possible that many of the aphasic subjects would not have been able to perform the task and important data would have been lost.

One other area of concern is that all subjects ate different meals. Although all meals consisted of the same categories of food--a main course, at least one side dish, a dessert, and a beverage--the types of food within each category varied greatly. One subject may have steak and potatoes while another had spaghetti and garlic bread and another had chicken fajitas and a side salad. Although each type of meal provided opportunity to use all three untensils (knife, fork, and spoon), it is possible that a subject may have received a meal that was easier or harder for him/her to eat than they would have normally chosen. However, controlling the type of food received by every subject was beyond the scope of this study. It is suggested that every opportunity be made in future studies to limit the variability of the food served.

A final consideration is that the subjects did not produce all of the error types proposed in Chapter One. This does not necessarily mean that the error types that were not demonstrated by the subjects do not exist. In fact, all error types discussed have been reported in other studies (Foundas *et al.*, 1995; Ochipa *et al.*, 1989; Mayer *et al.*, 1990; Schwartz *et al.*, 1991, 1993, 1995; and Schwartz & Buxbaum, 1997). It is possible that the error types that were not produced may be less frequently produced in general and that a larger number of subjects may have been necessary to provide ample opportunity for the less frequent error types to be produced.

A final concern pertains to the raters who scored the videotapes of the meal and documented the error types. The raters were not aware of the hypotheses of the study nor were they familiar with the Cognitive Neuropsychological Model of Limb

Praxis and Apraxia or the Unified Hypothesis. This was done to limit the effects of rater bias on judging the presence of action and movement errors and to strengthen the internal validity of the study. Only one previous study (Maher, 1995) has employed the same degree of control over this issue. As Maher (1995) reported, one possible limitation of this control is that the raters are dependent upon the trainer to accurately describe correct versus incorrect actions and movements. As a result, any biases the trainer may have could have influenced the raters. To control for this in the current study, the raters were given written descriptions of each error type and underwent a pre-scoring practice session of subjects not included in the study before undertaking scoring of actual videotapes from the subjects in this study. Therefore, the raters took their responsibilities seriously and were stringent in their decisions of whether an action or movement contained an error and then what type of error was demonstrated. Since the videotapes of all subjects were scored under these strict guidelines, it does not appear that rater bias affected the results.

Implications for Future Research

The results of this study are interesting and lead to further questions and possible research endeavors within the areas of limb praxis, pragmatic action, conceptual apraxia, and supervisory attention/working memory. Although the subjects in the current study had documented unilateral lesions, only laterality of lesion to the dominant (left) or non-dominant (right) hemisphere was taken into consideration. It is possible that mapping the size and location of the lesion within the hemisphere may lead to even greater conclusions regarding the relationship between brain-behavior relationships. This is especially true when the proposals for

location of the visuokinesthetic engrams for learned skilled movement associated with ideomotor apraxia have been determined to be in the inferior parietal lobule of the dominant hemisphere and that executive function disorders result from frontal lesion of either hemisphere. Therefore questions arise in that do all patients with frontal lobe lesions demonstrate high level schema deficits in the natural environment? Do patients with posterior lesions, especially left parietal lesions demonstrate low-level schema deficits in the natural environment?

Additionally, studies are indicated that use similar evaluation criteria of the independent variables in subjects with brain damage from different etiologies such as traumatic brain injury (TBI) and dementia. Although Schwartz *et al.* (1992, 1995) and Ochipa (1989) did evaluate patients with these different etiologies, both high and low level schema deficits were not systematically evaluated. Therefore, it is not known to what extent the role of high and low level schema deficits contributed to the production of action errors in their subjects.

Future studies should also take into consideration the possibility of observing brain-injured patients in their final type of residence. All of the subjects in the current study were evaluated either in a research laboratory, their room at a rehabilitation facility, or in the speech and hearing clinic associated with a university. This was done in order to control the categories of food the subjects received for their meals. However, it would be more "natural" to observe the subjects either within their own home or "final destination" (*e.g.*, an assisted living facility, adult family home, or skilled nursing facility) and eating food that they have chosen or prepared themselves. In addition, attempts should be made to observe or videotape the subjects without the

subjects being aware of the observation. All of the subjects in the current study were aware that they were being videotaped but were unaware of the nature of the study (*i.e.,* that their actions and errors were going to be examined). It is possible that just knowing that they were being videotaped led to increased consciousness of their actions.

Another lead for future studies would involve locating and evaluating subjects with only one deficit. For example, this might involve subjects with ideomotor apraxia who do not have executive function or supervisory attention/working memory disorders and so forth. By evaluating these "purer" subjects, a better understanding of the role of each type of disorder within the high and low schema frameworks may be delineated. Unfortunately, these subjects are rare and it is possible that the deficits described in the current study are more indicative of the "average" brain-injured patient.

Other issues that should be addressed in future studies include the relationship between neglect and the origination of the movements in space during activities of daily living. Do patients with neglect produce actions originating in the neglected hemispace during activities of daily living? Do their actions move into or end in the neglected hemispace? Also, does overall time to eat a meal or organization of the meal differ across left and right hemisphere damaged patients? Foundas *et al.* (1995) reported that time to eat was longer for the left hemisphere damaged patients than for the controls and that the left hemisphere damaged patients did not respect the boundaries of the different meal stages. It is not known whether patients with right hemisphere damage would demonstrate these same deficits.

In all, research into the nature of action and movement errors in activities of daily living, pragmatic action, and real-life effects of ideomotor apraxia appear to be exciting, clinically relevant, and productive endeavors.

Clinical Implications

The degree to which action errors were produced by patients in the current study is interesting in that none of the caregivers (*i.e.*, nurses or family members) reported that the patient had been producing errors. Additionally, there is a scarcity of reports in the literature that describe errors of action produced in natural contexts by a group of brain damaged patients. Since twenty-four of the thirty brain damaged patients in the current study produced errors of action following a unilateral stroke, it is very probable that these errors of action go undetected within the controlled environment of an acute care hospital, rehabilitation center, or nursing home. It is also feasible that any person who suffers a brain injury is susceptible to produce action errors secondary to high level schema deficits that follow damage to either hemisphere. If this is true, then there are significant implications for caregivers and rehabilitation professionals for these brain-injured people. The caregivers should be aware of the potential danger in which the brain-injured patient is placed when in an unsupervised or uncontrolled environment. One example described by Ochipa (1989) was of a patient who was preparing to brush teeth in the bathroom but picked up the razor instead of the toothbrush. The inherent danger in that scenario is obvious to even those not familiar with deficits seen following brain injury. However, in order to control potentially dangerous situations, the caregiver must be made aware of the possibility that the brain-injured patient can and will produce these action errors.

Unfortunately, this is an area about which not many rehabilitation professionals are aware and subsequently may not adequately inform the caregiver (Ochipa, 1989; Foundas *et al.,* 1995). Moreover, once caregivers are made aware of the possibility of putting the brain-injured patient in dangerous situations, the management of the problem is relatively easy to administer. The management involves educating the caregiver and any other significant individual who will be working with that patient as to ways of controlling the environment so as not to put the individual at risk. These suggestions for management were described by Ochipa (1989) and are reiterated here:

1. Limit access to dangerous tools (knives, razors, *etc.*).
2. Limit the available selection of tools for a particular task (*e.g.* a razor should not be within reach when the person is brushing his/her teeth).
3. Tools should only be used in tasks that are familiar to the patient. Tool use in novel or new contexts should be avoided.
4. Tasks involving the use of multiple tools should be avoided.
5. Any task that requires the use of potentially dangerous tools should be strictly supervised.

Additionally, presence of dysphagia (swallowing disorders) in brain-injured patients is also high (Although not specifically addressed in the current study as subjects with dysphagia were specifically excluded). It is highly probable that the combination of action errors with swallowing problems during mealtime may put the brain-injured subject at higher risk for choking or aspiration. Especially when it is considered that the most prevalent action errors were misuse and quantity. The

possibility of a brain-injured patient with dysphagia bringing a utensil to his/her mouth with too much or too little food is very possible and may result in exacerbation of the swallowing problem.

The role of the speech-language pathologist (SLP) is an important one when action errors in the natural environment are discussed. The SLP is usually in a unique relationship with the brain-injured patient and their caregivers in that the SLP's main role is to improve the functional communication of the patient as well as to evaluate and treat dysphagia. By doing these tasks, the SLP becomes very familiar with the patient and their family and is often asked to interpret or reiterate instructions and conversations by other health care professionals. Through these close relationships, the SLP is accountable for providing ethical and professional care to the patient. The SLP's responsibilities often include counseling patients and caregivers, providing input to the rehabilitation team for discharge options, level of communication function, need of home health aids or assistance, as well as being an "intermediary" between the level of communication competence of the rehabilitation professionals and the level of communication competence of the brain-injured patient and their caregiver, who may be ignorant of the health care process. In these scenarios, the responsibility is also placed on the SLP to be accountable and knowledgeable for areas that may detrimentally affect their patient, of which production of action errors is one category.

APPENDIX A

FLORIDA APRAXIA BATTERY - GESTURE TO COMMAND SUBTEST
RANDOMIZED FORM A

NAME: DATE:

Subjects will be required to provide a gesture to the given command. Subjects are to use the left (ipsilesional) hand to gesture. The first time the subject produces a body part as tool error, remind subject to pretend to hold and use the tool just as he normally would at home. Then allow to reattempt the gesture. Do not reinstruct on subsequent errors. Videotape all responses from a front view with subject seated in a chair. Although general performance may be scored on-line, actual scores will be derived from videotape viewing.

Instructions: "I am going to ask you to make some gestures with your left hand. For some gestures you will just make different hand motions. For others you will pretend to use certain tools. Pretend to use each tool just as you would if you were actually holding the tool in your hand and using it."

Show me:	Score	Error Code
1. how to use a scoop to serve ice cream.	_____	_____
2. stop.	_____	_____
3. how to use scissors to cut paper.	_____	_____
4. OK.	_____	_____
5. how to use wire cutters to snip a wire.	_____	_____
6. how to use an ice pick to chop ice.	_____	_____
7. how to use a comb to fix your hair.	_____	_____
8. how you make a fist.	_____	_____
9. how you wave good-bye.	_____	_____
10. someone is crazy.	_____	_____

FAB Gesture to Command, cont.
Randomized form A

NAME:

11. how to use a salt shaker to salt food. _____ _____

12. how to use a pencil to write on paper. _____ _____

13. how to use a glass to drink water. _____ _____

14. how you salute. _____ _____

15. how to use a hammer to pound a nail into a wall. _____ _____

16. how to use an eraser to clean a chalkboard. _____ _____

17. how to use a spoon to stir coffee. _____ _____

18. how to use a brush to paint the wall. _____ _____

19. how to use a screwdriver to turn a screw into the wall. _____ _____

20. how to use a bottle opener to remove a bottle cap. _____ _____

21. go away. _____ _____

22. how to use an iron to press a shirt. _____ _____

23. how to use a razor to shave your face. _____ _____

24. come here. _____ _____

25. how to use a knife to carve a turkey. _____ _____

26. how you hitchhike. _____ _____

27. be quiet. _____ _____

28. how to use a key to unlock a doorknob. _____ _____

29. how to use a saw to cut wood. _____ _____

30. how to use a vegetable peeler to shred a carrot. _____ _____

FLORIDA APRAXIA BATTERY - GESTURE TO COMMAND SUBTEST
RANDOMIZED FORM B

NAME: DATE:

Subjects will be required to provide a gesture to the given command. Subjects are to use the left (ipsilesional) hand to gesture. The first time the subject produces a body part as tool error, remind subject to pretend to hold and use the tool just as he normally would at home. Then allow to reattempt the gesture. Do not reinstruct on subsequent errors. Videotape all responses from a front view with subject seated in a chair. Although general performance may be scored on-line, actual scores will be derived from videotape viewing.

Instructions: "I am going to ask you to make some gestures with your left hand. For some gestures you will just make different hand motions. For others you will pretend to use certain tools. Pretend to use each tool just as you would if you were actually holding the tool in your hand and using it."

Show me:	Score	Error Code
1. how to use an eraser to clean a chalkboard.	_____	_____
2. how to use a spoon to stir coffee.	_____	_____
3. how to use a brush to paint the wall.	_____	_____
4. how to use a screwdriver to turn a screw into the wall.	_____	_____
5. how to use a bottle opener to remove a bottle cap.	_____	_____
6. go away.	_____	_____
7. how to use an iron to press a shirt.	_____	_____
8. how to use a razor to shave your face.	_____	_____
9. come here.	_____	_____
10. how to use a knife to carve a turkey.	_____	_____
11. how you hitchhike.	_____	_____
12. be quiet.	_____	_____

FAB Gesture to Command, cont. NAME:
Randomized form B

13. how to use a key to unlock a doorknob. _____ _____

14. how to use a saw to cut wood. _____ _____

15. how to use a vegetable peeler to shred a carrot. _____ _____

16. how to use a scoop to serve ice cream. _____ _____

17. stop. _____ _____

18. how to use scissors to cut paper. _____ _____

19. OK. _____ _____

20. how to use wire cutters to snip a wire. _____ _____

21. how to use an ice pick to chop ice. _____ _____

22. how to use a comb to fix your hair. _____ _____

23. how you make a fist. _____ _____

24. how you wave good-bye. _____ _____

25. is crazy. _____ _____

26. use a salt shaker to salt food. _____ _____

27. use a pencil to write on paper. _____ _____

28. use a glass to drink water. _____ _____

29. how you salute. _____ _____

30. how to use a hammer to pound a nail into a wall. _____ _____

APPENDIX B

TOOL-OBJECT MATCHING TASK

Procedure: Place the target tool and three foil tools in random order in front of the subject. Place the object with the partially completed action behind the tools.
Instructions: "I am going to show you some tools and an object in which an action has not been completed. Please choose the tool that you would use to complete the action."

Objects with partially completed action	Target tool	Foil #1	Foil #2
1. half opened can	can opener	saw	pen
2. nail half in wood	hammer	screwdriver	needle
3. bit half in wood	hand drill	wrench	staple remover
4. partially sawed board	saw	hammer	scissors
5. partially sewed cloth	needle	can opener	scissors
6. half drawn picture	pen	needle	hand drill
7. nail bent in wood	hammer	wrench	saw
8. partially cut paper	scissors	pen	staple remover
9. screw half in wood	screwdriver	wire cutters	hammer
10. staple half out of paper	staple remover	can opener	wire cutters
11. partially cut wire	wire cutters	hand drill	hammer
12. nut & bolt partially tightened in wood	wrench	hammer	screwdriver

APPENDIX C

TRAILS TEST: Time in Seconds (on Parts A and B) for Normal Control Subjects at Different Age Levels

	15-20 Years (n=108)		20-39 Years (n=275)		40-49 Years (n=138)		50-59 Years (n=130)		60-69 Years (n=120)		70-79 Years (n=90)	
Percentile	A	B	A	B	A	B	A	B	A	B	A	B
90	15	26	21	45	18	30	23	55	26	62	33	79
75	19	37	24	55	23	52	29	71	30	83	54	122
50	23	17	26	65	30	78	35	80	35	95	70	180
25	30	59	34	85	38	102	57	128	63	142	98	210
10	38	70	45	98	59	126	77	162	85	174	161	350

Data extrapolated from Table 8-12 in Spreem and Strauss (1991) A Compendium of Neuropsychological Tests, London: Academic Press, p. 376.

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BIOGRAPHICAL SKETCH

Beth Lynn Martin Macauley was born on December 9, 1965, in Sanford, Florida, to John L. and Barbara A. Martin. She has one younger brother, John William (Billy) Martin who is an architect in Charlotte, North Carolina. Beth married Shawn P. Macauley on June 18, 1988, in Port St. Lucie, Florida. They have two beautiful daughters, Erin Elizabeth born December 11, 1990, and Emily Logan, born February 23, 1995, both in Gainesville, Florida, and one handsome son, Evan Alexander, born March 29, 1998, in Spokane, Washington.

Beth graduated from Ft. Pierce Central High School, Ft. Pierce, Florida, in June 1983, ranked 12th out of 364 graduates. She began her college career at the University of Florida in the fall of 1983 and graduated with a B.A. degree in speech-language pathology and audiology in May 1987. Beth continued on in graduate school at the University of Florida and received her M.A. degree in speech-language pathology in December 1989. Her master's thesis was a unique study that combined her first love, speech pathology, with her main hobby, working with horses. The title was "The effects of hippotherapy on the respiration and motor speech functions of two females with cerebral palsy." Beth continued her training by completing the clinical fellowship year (CFY) in speech-language pathology in the Department of Communicative Disorders at W.A. Shands Hospital, Gainesville, Florida, under the supervision of Kenneth Bzoch, Ph.D., Lowell Hammer, Ph.D., and Michael Crary, Ph.D. Beth received her Certificate

of Clinical Competence in speech-language pathology from the American Speech-Language-Hearing Association in October 1990.

Following her CFY, Beth returned to full-time graduate work to pursue the doctoral degree under the mentorship of Leslie J. Gonzalez-Rothi, Ph.D., at the University of Florida. Beth's focus was on neurogenic communication disorders with special emphasis in neuropsychology. During her doctoral years, Beth worked as a research assistant for Kenneth M. Heilman, M.D., a behavioral neurologist in the Department of Neurology, University of Florida College of Medicine and the Center for Neuropsychological Studies. She also worked as a speech-language pathologist for Special Communications and Continental Medical Systems Therapies (now Pro-Rehab, Inc.). Special Communications served state institutions for mentally and physically handicapped people and CMS Therapies served two skilled nursing facilities the Gainesville area.

From 1985 through 1994, Beth worked at Florida Horsemanship for Handicapped, Inc., as a junior instructor and therapist. She represented the program at the 6th International Congress on Therapeutic Riding in Toronto, Ontario, August, 1988, and the North American Riding for the Handicapped Association convention in Parsippany, New Jersey, November, 1989. Beth was also active in the Florida Blue Key Honor Fraternity, serving as service chairman 1991-1992, the Collegiate 4-H Club, serving as secretary and vice-president 1984 and 1985, respectively, and the National Student Speech-Language-Hearing Association, serving as president for the 1987-88 school year.

Toward the end of her doctoral program, Beth applied for various faculty positions and was extended an invitation to join the faculty in the Department of Speech

and Hearing Sciences at Washington State University, Spokane, Washington. Her husband was also extended an offer to join the Health Research and Education Center and the Department of Genetics and Cell Biology at Washington State University. They accepted and began work in December 1995. While in Spokane, Beth has worked as a weekend rotation and on-call speech-language pathologist for Empire Health Services which serves Sacred Heart Medical Center, Deaconess Medical Center, Valley Hospital and Medical Center, and St. Luke's Rehabilitation Institute. She is also a consultant speech-language pathologist for Paul J. Domitor, Ph.D., a Spokane based clinical psychologist and for A-Stride Ahead Therapy Services, a hippotherapy program in Deer Park, Washington. Upon completion of her Ph.D., Beth will continue as an Assistant Professor in the Department of Speech and Hearing Sciences at Washington State University.

In Spokane, Beth is active at Garland Avenue Alliance Church, singing in King's Praise adult choir and playing flute with the worship orchestra. Her interests include riding and showing horses, playing the flute, sewing, cross-stitch, and baking.

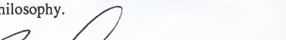
I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Leslie J. Gonzalez-Rothi
Associate Professor of Communication Sciences and Disorders

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Kenneth M. Heilman
Professor of Clinical and Health Psychology

I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.



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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

Ira Fischler
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This dissertation was submitted to the Graduate Faculty of the Department of Communication Processes and Disorders in the College of Liberal Arts and Sciences and to the Graduatre School and was accepted as partial fulfillment of the degree of Doctor of Philosophy.

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